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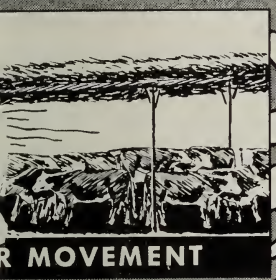

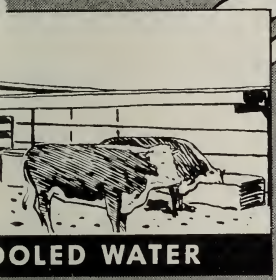

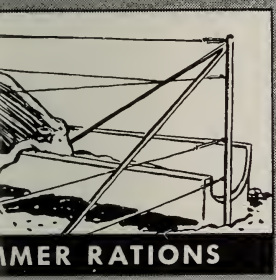

Methods of Increasing Beef Production in Hot Climates

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CALIFORNIA AGRICULTURAL EXPERIMENT STATION

BULLETIN 761

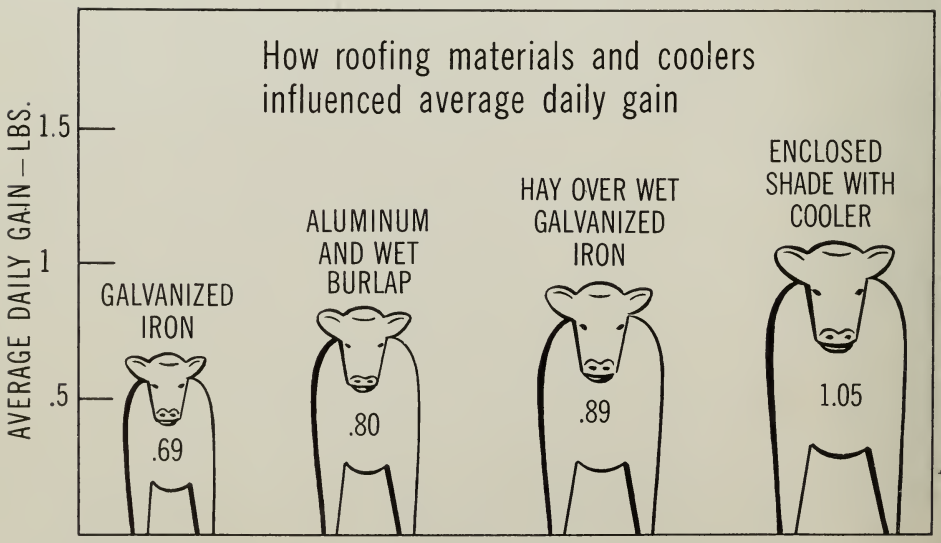
Fifty-one per cent of the cattle in the United States, representing a cash value of 7⅕ billion dollars, are in areas where the average summer temperature is above 75° F. Because many of these areas are close to important markets, have plentiful supplies of water and high quality feeds, cattlemen have for a long time been interested in improving their beef production in such hot areas, notably the deserts of California.

Experience and experiments have shown that beef production drops considerably in hot summers as cattle become uncomfortable and eat less.

Since 1946 the Animal Husbandry and the Agricultural Engineering departments of the University of California in cooperation with the United States Department of Agriculture have been conducting experiments at the University experiment station in El Centro, California, to study the effect of different hot weather environments on beef cattle. The goal of the experimenters has been to devise means whereby cattlemen could make their beef animals more comfortable during the hot months and carry out profitable year-round operations.

The experiments have resulted in a number of practical applications which may be carried out by farmers at minimum expense. The steps to be taken to maintain animal comfort and production revolve around five key factors . . . Shade . . . Water . . . Air Movement . . . Radiation . . . Feed.

SHADE . . . Properly designed shades will reduce the radiation heat load on cattle up to 50 per cent. Most shades in the desert areas are from 16 to 20 feet wide and up to several hundred feet long. Experiments indicate that 10 to 12 feet is the best height for a cattle shade.



OW BETTER DAILY GAINS IN WEIGHT

Although east-west orientation is best from the standpoint of reducing radiation heat load, experimenters found that shades oriented north and south, so that the sun would cover the entire area for part of the day, improved sanitary conditions.

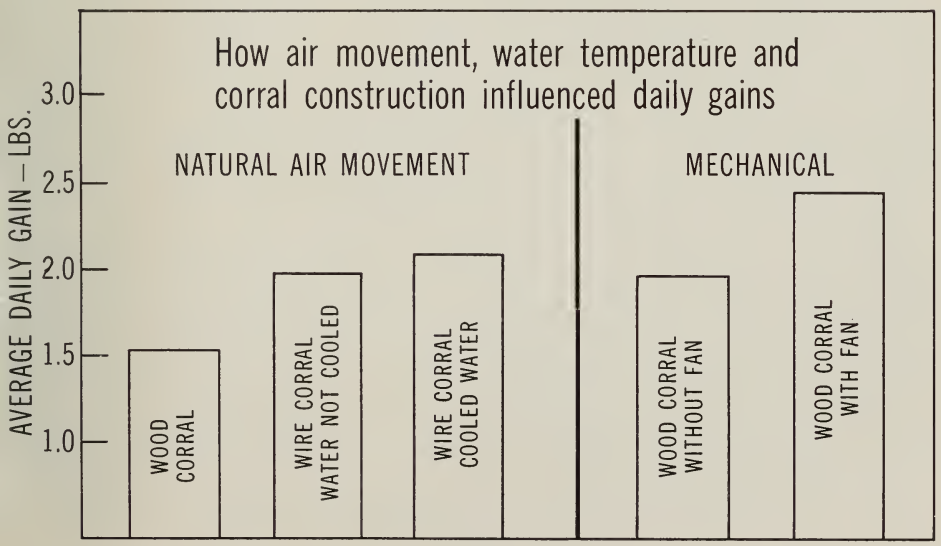
The experimenters used galvanized steel sheets, aluminum sheets, boards and hay as roof material. Hay proved to be the coolest of all materials tested although it provides problems of replacement, protection from wind and damage when wet by rain. Hay should be held together by two layers of wire net to reduce blowing.

It was also found that by painting the top side of metal white, the radiant heat load under the shade could be reduced considerably. Painting the underside of a metal roof black also was found to be an aid in reducing radiant heat load on the animals because the dark paint absorbed radiation from the ground rather than reflecting it back onto the animals.

Although tests were not conducted to ascertain the shade space requirement per head, it is believed 60 square feet per head is adequate. The important thing to remember is to avoid crowding during summer months. A complete summary of shade experiments may be found on page 32.

WATER . . . Experiments were conducted to increase animal gains by using water to wet the cattle in pens and by cooling drinking water.

The use of sprays, hoses and other methods of wetting animals was not too successful unless the animals were wetted to the skin. Investigators believe that the humidity increase occasioned by the use of water may slow the evaporation of moisture from the cattle, and in fact make it more difficult for them to retain thermal balance.



They do however feel that such programs may be of value in areas less humid than the location of the experiment station.

The cooling of drinking water on the other hand did appreciably increase animal comfort and production. By keeping drinking water at about 65° F., noticeable gains were reported. While mechanical refrigeration costs are probably too high for commercial programs, other methods of cooling were suggested. Evaporative water towers helped keep water cool. By using underground pipes from wells where the water was already at a low temperature, experimenters were able to obtain cool water at little or no extra cost. By keeping water in shallow tanks so that cool water could not be reached by the cattle and by covering tanks except for small drinking holes low temperatures were maintained. Shaded drinking tanks also proved valuable but shades should not be large enough to allow animals to stand under them. A complete summary of experiments with water is on page 50.

AIR MOVEMENT . . . Increased air movement has proven to be of great benefit to cattle. Either mechanical or natural means can be utilized to increase the circulation of air in cattle pens.

Without incurring extra expense cattlemen can take advantage of natural conditions to increase circulation by proper corral construction. Wire or cable corrals offer little resistance to natural air movement and during tests resulted in significant gains compared to cattle penned in wooden corrals. Proper orientation of corrals to take advantage of air movement in the area is also important.

The experimenters successfully employed large fans, operating either full or part time, to increase air movement over penned cattle. Even though penned in wooden corrals, cattle subjected to mechanical air movement made better gains than animals in wooden corrals without fans. Experimenters feel that the gains more than offset the cost of operating fans.

Although cattle are not considered to be sweating animals, recent studies indicate that they may lose a large amount of moisture through the skin and that increased air movement speeds up evaporation of the moisture and brings about more rapid cooling. A complete summary of air movement experiments can be found on page 66.

RADIATION . . . The sky, the ground, the corral, nearby buildings, literally everything in sight, radiates heat onto the cattle. Reducing this radiation is a complex but not insoluable problem.

Corral construction, which plays an important role in promoting increased air circulation, is also important in controlling radiation. Wire or cable, because it offers relatively little area for absorbing or reflecting heat, has proven much better than wood for this purpose. The fences in a wooden corral absorb a great amount of heat and radiate it directly back onto the penned cattle.

Buildings, hay stacks, large farm machines and other obstacles which would radiate heat should not be located near corrals. This will also permit free circulation of the air.

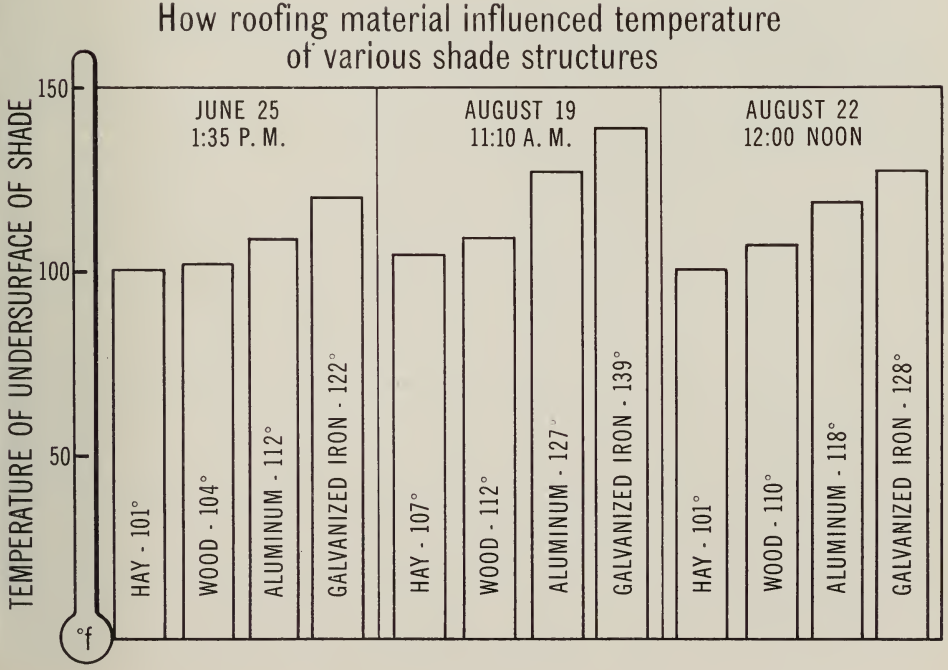
If at all possible cattle pens should be located near growing crops. Cattle in pens in such surroundings showed much better gains than

animals subjected to radiation from the bare earth, roads or other surfaces. Air temperatures in the vicinity of growing crops were significantly lower.

Experiments with special electronic equipment revealed that the north sky usually is cooler than the rest of the sky. The temperature of the sky was measured. Orientation of shades and fences so that animals can be exposed to this cool area of the sky is another factor in promoting animal comfort. A summary of radiation experiments can be found on page 75.

FEED... The proper ration for hot weather is extremely important in beef production. Care should be taken not to supply high fibre diet during hot months. Such feeds produce a high "heat increment" which must be dissipated by the body, a difficult task in hot weather. In general, a summer ration should be good quality roughages and grains.

In general, cattle in the desert with proper shade, corrals, water and diet can be expected to gain two pounds per day or more. However, experimenters found that it was advisable to bring cattle into the desert area before the mid-summer heat so the animals could become accustomed to the high temperatures of that period gradually. Best results were obtained if the animals were brought to top finish in the spring or fall, rather than in the heat of the summer. A complete summary of feeding experiments may be found on page 78.



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APRIL 1958

METHODS OF INCREASING BEEF PRODUCTION in HOT CLIMATES*

N. R. ITTNER • T. E. BOND • C. F. KELLY

Introduction

Why, how, and when the studies described here were conducted

Reasons for Study

The heat load on animals is high during the summer in the Imperial Valley, Coachella Valley, Palo Verde Valley, and other desert areas of California. Environmental studies to determine ways and means of making livestock more comfortable during the hot weather have been in progress at the University of California's Imperial Valley Field Station since 1946.

Heat in this area is generally of the dry type although there are about six weeks every summer when a humid condition develops from moist air blowing in from the Gulf of California.

The adverse effects of a hot environment on livestock are more pronounced than those of a cold environment. Various studies have shown the effect of heat on livestock, with dairy cattle at the University of Missouri (Ragsdale, Brody, et al., 1948) and California (Regan and Richardson, 1938), with swine at the University of California (Heitman and Hughes, 1949), with poultry at the Beltsville (U.S.D.A.) Research Center (Ota, Garver, and Ashby, 1953), and with beef cattle at the Imperial Valley Field Station (Ittner and Kelly, 1951). All of these investigations have shown that the depressive effects of heat begin to be felt at a relatively low temperature level, around 75° F.† This is known as the critical temperature and can be defined as the air temperature beyond which cattle begin to have a higher than normal body temperature.

There are many areas in the world where high temperatures are a problem in livestock production. Here in the United States the 75° isotherm (fig. 1) divides the country into two parts: All of the area south of the line has an average temperature above 75° during July, which is the hottest month in all parts of the country, except along the Pacific Coast, where August is hotter. The region south of the isotherm contains 51 per cent of all the beef cattle and calves and dairy cattle (including

* Submitted for publication April, 1957.

† All temperatures in this bulletin are on the Fahrenheit scale.

heifers over two years old) of this country (U.S.D.A. Agriculture Statistics, 1953). Their 1953 value in farm and ranch was over 7⅕ billion dollars, out of a total for the country of 16⅘ billion dollars.

In many parts of the world, work is in progress to develop more productive animals that are adaptable to their particular hot climate. In the southern part of the United States much of this work is being done with Brahmans or Brahmans crossed with the exotic breeds and with the Charolais cattle of France. The King Ranch in Texas has developed the Santa Gertrudis breed by crossing the Brahman and Shorthorn (Rhoad, 1955). In our country we usually think of the Brahman as the only heat-tolerant animal, but there are a number of other areas that have heat-tolerant, indigenous types of cattle, such as the Boran cattle of Kenya, the N'dama in French Guinea, or the Criollo cattle of Venezuela. Considerable improvement can be, and has been made through selection, but this method has its limitations and progress is slow. New improved types can be developed faster by crossing these indigenous types with one of the more productive breeds. South Africa is using the Africander with the Hereford and Shorthorn to get a more desirable beef type adaptable to their conditions. Much progress is being made along these lines, but all are long-range programs which no doubt will eventually provide the hot regions of the world with more productive types of animals.

A more immediate approach to this problem was needed for our desert areas since more and more cattlemen are operating on a year-round basis. The environment project described herein was

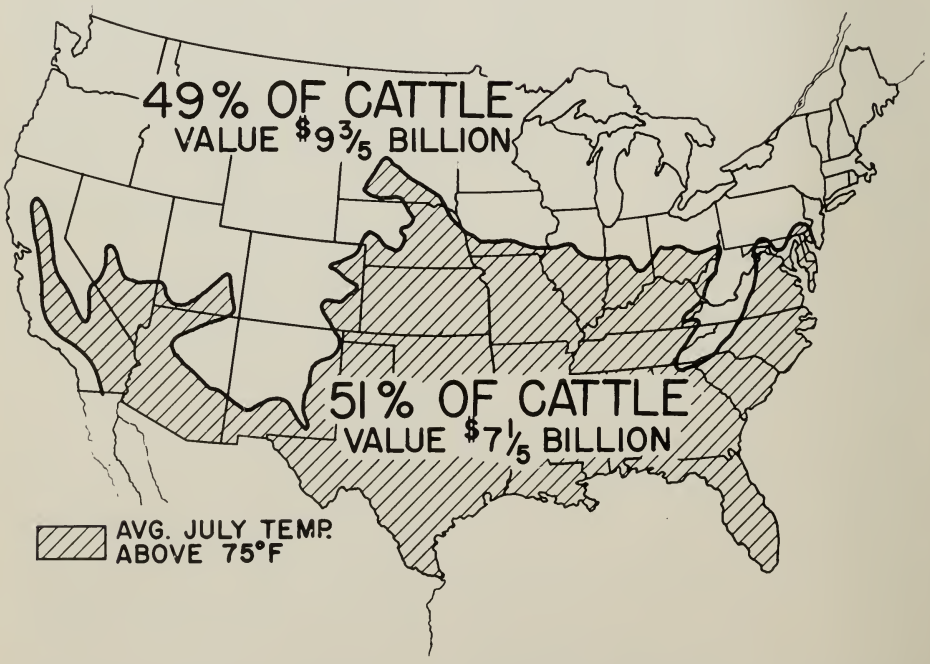


Fig. 1. 75° F isotherm for average July air temperature in the United States, and number and value of livestock in areas north and south of isotherm (U.S.D.A., Agric. Statistics). (Isotherm from Climate and Man, U.S.D.A. Yearbook, 1941.)

established to find ways of reducing the heat load on animals, and the results of the last ten summers' experiments are discussed in this bulletin. Some of the methods tested have proved to be very helpful, while others have not proved to be too practical. The results of these experiments will be discussed and illustrated and methods of application to a livestock program will be recommended. Many of the methods are also applicable to heat-tolerant animals since they perform better under less rigorous conditions. Nearly all of the tests were made with Hereford cattle since they seem to be the most heat-tolerant of the European breeds and are the popular breed in the west.

Effect of High Temperatures on Production

Heat tolerance is the term applied to the animal's ability to escape the adverse consequences of a hot environment. Just what constitutes heat tolerance in an animal is not definitely known, but all the evidence points to the fact that it is a complex entity. It is known that tropical cattle have a higher heat tolerance than temperate-zone cattle, and among the European cattle some breeds have more heat tolerance than others. Body temperature is one way of checking heat tolerance (Rhoad, 1944). Bonsma (Bonsma and Pretorius, 1943) in South Africa has done a great deal of work with cattle in tropical environments and has shown that short-haired cattle have a lower body temperature and grow faster than those with woolly coats. He has also shown that light-colored cattle reflect more solar heat than those with dark hair. An animal's suitability to an environment is indicated by heat tolerance, growth, feed efficiency, high fertility, and low incidence of disease. The indigenous cattle found in the semi-arid subtropics are usually rather large-framed animals like the Africander. In the humid tropics heat dissipation is most difficult so an animal with a large skin area per unit weight is desirable. These characteristics are found in the small Nguni breed of South Africa.

Many livestock men and scientists throughout the world have noted that when European breeds of cattle are moved away from the cool climatic conditions of their native home and placed in a hot environment they show marked distress and low productivity. Some of this distress and low productivity is undoubtedly due to the plane of nutrition, the parasitic condition of the animals, and management practices, all of which, more often than not, are quite different from what they have been accustomed to. Internal and external parasites are usually more severe in a hot, humid climate than in a hot, dry climate. California's desert areas are hot and dry most of the year, and the parasitic problems are not serious. Anaplasmosis is one parasite that has been a problem from time to time. With the increasing numbers of animals, parasites are likely to become more of a problem. However, it should be remembered that sanitation is the answer to many disease problems and good hot sunlight is one of our best disinfectants.

Except for the summer heat, this region is an ideal place to feed cattle. There is an abundance of feed, such as alfalfa, sudan, barley, and milo. There is also plenty of cheap irrigation water and very little rain to create a mud problem for the cattle. Last but far from least, is the region's proximity to the growing Los Angeles market.

Heat in this area is severe enough to materially reduce the daily gain of beef cattle, and dairy cattle have more than a normal drop in milk production. When the body temperature rises, usually at air temperatures of 75°–80° F for European and 95° F for Indian cattle, the animals lose appetite and reduce feed intake; this reduces their metabolic rate and keeps them cooler, but it also re-

duces daily gain and milk production (Worstell and Brody, 1953).

Cattle in this region show little loss of production with daytime temperatures of 110° to 115° F if the night temperature drops to around 60° F. When the maximum temperature is 105° F and the minimum is 80° F for two or three days, there is an immediate drop in food consumption and reduction in daily gain.

Most of the environmental studies reported herein have used summer gains and feed efficiency of beef cattle as indices for testing different feeds and management practices. Cartwright (1955) reports that summer gains are sufficiently high in heritability (19 per cent) to be useful in selecting breeding animals.

Although considerable information has been gathered throughout the world on the reactions of cattle to thermal stress, there is still a great deal that is not known concerning the fundamental physiology of temperature regulation in cattle, as well as the anatomical differences responsible for their adaptability to heat.

A Basic Approach to the Problem

An animal is continually producing heat from the feed it consumes. Since only a part of this feed energy is utilized in the production of milk, meat, and fat, and for body maintenance, the excess must be disposed of. For an animal to be thermally comfortable there must exist a balance between the energy added to it and that utilized by, or removed from it. The problem of keeping livestock cool during hot weather is essentially one of aiding the animal to maintain a proper energy balance. It is quite possible to control or modify most of the factors affecting this balance. To understand better how this may be accomplished and to form a basic approach to the problem, it is essential to consider the four modes by which heat, or energy, is transferred between an animal and its environment.

Convection: By convection an animal can lose heat to, or gain heat from, air circulating around it, depending on whether this air is cooler or warmer than the animal surface. The amount of heat exchanged is controlled according to the relationship:

$$Q_c = CAV^n (t_1 - t_2)$$

Here Q_c is the convective exchange of heat, V is the air velocity, A is the animal surface area, $(t_1 - t_2)$ is the temperature difference between air and animal surface, and C is the convection constant. The amount of heat exchanged varies linearly with animal surface area and with the temperature difference between animal surface and air. It varies nonlinearly with air velocity (wind). The value of the coefficient C is dependent upon the characteristics of the surface (in the case of cattle the length and thickness of hair, how much hair, and whether curly or straight). The value C also depends upon the direction of air flow with respect to the surface.

Evaporation: For each pound of moisture evaporated, about 1050 Btu of heat are exchanged. The rate of energy exchanged between the surrounding air and an animal's surface can be described by an equation of the type,

$$Q_e = KAV^n\lambda(p_s - p)$$

Here Q_e is the evaporative heat exchange, V is the air velocity, A is the animal surface area, λ is the latent heat of vaporization of water, $(p_s - p)$ is the difference in partial pressure of the water vapor at the animal surface and in the surrounding air, and K is the evaporative constant, which, like the convective coefficient is affected by the type of surface and its directional relationship to the flow of air. The air velocity exponent, n, is similar to that in the convection equation above which means that evaporative

and convective exchanges of heat are similarly affected by wind. In the case of beef cattle, as with most livestock, moisture is also removed from the respiratory areas, and the amount of heat exchanged by this method is greatly affected by the rate and extent of respiratory activity.

Radiation: All surfaces radiate, absorb, and reflect energy (heat) in amounts dependent upon the temperature and character of the surface. Any two surfaces, then, are continually exchanging heat at a rate defined by the equation,

$$Q_r = A\,\sigma F_a F_e\,(T_1^4 - T_2^4)$$

Here Q_r is the radiation heat exchange, A is the area of one surface, σ is the Stefan-Boltzman constant, F_a is a factor that allows for the relationship of one surface to another (sometimes called "shape" or "seeing" factor), and T_1 and T_2 are the absolute temperatures of the two surfaces. The factor F_e allows for the radiation characteristics, emissivity* and absorptivity†, of the two surfaces.

Conduction: Heat is transferred by conduction through an object if there is a temperature gradient present, or from a warm surface in contact with a cooler surface, at a rate determined by the equation,

$$Q_k = UA\,(t_1 - t_2)$$

Here Q_k is the conductive heat transferred, A is the area through which heat is transferred, $(t_1 - t_2)$ is the temperature gradient through the object or between two surfaces, and U is the over-all heat transfer coefficient of the system. Conduction is perhaps the least important of the four modes by which heat is exchanged externally by an animal. There is also some exchange of heat with surrounding air by conduction.

Treatment of these four modes of heat exchange has been highly simplified for sake of illustration. Also, they have been treated as being independent. For inanimate objects independent treatment is often possible—for an animal it is not. For example, environmental temperature affects the surface temperature of animals so that any change in environmental temperature is accompanied by a change in surface temperature. The equations given above show that each mode of heat exchange is affected by the respective levels of these two temperatures (in the evaporation equation the vapor pressure is a function of temperature). All other factors affecting heat exchange are equally interdependent so that approaching the problem of cooling livestock solely on a theoretical basis is highly illogical. The other approach is experimental.

The four equations point out all the factors affecting thermal comfort of animals. Since any improvement of the thermal comfort of an animal must be made through some modification or control of these factors, these are listed below and they define what areas can and should be investigated to provide thermal relief for animals in a hot environment. This was the approach that guided the research reported in this bulletin.

A. *Air*
- Temperature
- Humidity
- Velocity
- Direction

B. *Animal*
- Surface temperature
- Surface area
- Surface characteristics
- Surface evaporation
- Breed
- Feed
- Water

*Emissivity: the ratio of the intensity of radiation of any given wavelength emitted from unit area of a surface to the intensity in the same wavelength from unit area of a black body at the same temperature.

† Absorptivity: the fraction of incident radiation absorbed by a substance. At any wavelength and temperature the absorptivity of an opaque substance is equal to its emissivity or to one minus its reflectivity.

C. *Surroundings*
- Temperature of surrounding surfaces
- Radiation characteristics of surrounding surfaces
- Location with respect to animals
- Solar and sky radiation

Cooperative Nature of Study

Cooperative programs in research are imperative if scientific information is to continue to expand. This study has three cooperators, the Animal Husbandry Department and the Agriculture Engineering Department of the University of California and the United States Department of Agriculture. All three have contributed men, money, and materials for the development of this program. Since these experiments are primarily a study of the heat exchange between the animal and its environment, many engineering instruments have had to be used in order to measure heat flow both to and from the animal. Evidence is beginning to accumulate that the gaining ability of cattle in a hot environment is directly related to its comfort and heat tolerance.

The Climate

Factors that make beef raising difficult in the desert area

Air Temperature, Wind Velocity and Relative Humidity

Two terms used for the classification of summer weather are "hot dry" and "warm humid." These two conditions occur in nature, but quite often any one place will have variations or combinations of these two types of weather during the summer. Death Valley in California is an example of a hot, dry area, while the states bordering on the Gulf of Mexico have warm, humid summers.

A hot, dry environment is characterized by high air temperatures, low humidity, and dry ground with little or no vegetation. Such conditions provide very few clouds or moisture vapor in the air to remove the intense rays of the sun. These high temperatures and direct solar radiation are bad, but there is also the intense reflection of the sun's radiation from the dry ground. However, there are two factors operating here which prevent these conditions from becoming unbearable: one is the dry air which facilitates evaporation of water, and the other is the clear sky which allows considerable heat from the ground to radiate into the upper stratosphere.

Warm, humid climates are characterized by clouds and moist air, which remove some of the solar radiation, and vegetative cover which reduces the radiation heat load from the ground. Air temperatures in these climates are moderate and seldom above the animal's skin temperatures, but the evaporation of water is very slow. Most people find the wet, sticky condition of the skin distinctly uncomfortable in these regions. Increasing air movement in a humid area aids in the evaporation of water and makes life more comfortable to human beings. High winds with high temperature and a low humidity can be most uncomfortable because of their drying effect on the body.

Imperial Valley, Coachella Valley, and Palo Verde Valley are, in many respects, typical of a hot, dry region, but for about six weeks every summer these valleys become hot and humid. This phenomenon is brought about by a prevailing wind from the south, bringing moisture

from the Gulf of California. During the remainder of the year the prevailing wind is from the west. This six-week period also has a number of tropical thunder showers, usually local and at times quite destructive. Relative humidity readings are usually below 40 per cent during the heat of the day and more often than not range betwen 15 and 35 per cent. When the noon humidity is 30 per cent or above, human beings become uncomfortable. Fortunately, excessively high temperatures do not usually prevail during this humid period; maximum temperatures range between 100° and 105° F. However, minimum temperatures become excessive, seldom dropping below 70° F. Furthermore, they are seldom below 80° F for more than four hours. The moisture-laden air from the Gulf radiates the heat back to the earth instead of letting it dissipate in the upper atmosphere. Since the ground cannot cool, night temperatures rise and the mean temperature for the 24-hour period goes well above the critical temperature for cattle (75–80° F) with a consequent drop in production. There are periods when the night temperature does not drop below 80° F for 15 to 20 days at a time.

These desert areas have a mean monthly temperature above 75° F for about six months of the year; for nearly four months it exceeds 85° F and for two months it is 90° F. Figure 2 shows the temperature and humidity for a typical hot, dry day and a hot, humid day for the Imperial Valley.

Air movement during the summer is negligible, although for an hour or so winds may reach velocities of 40 to 50 miles per hour. The average wind velocity during the summer is around 2.5 miles per hour 3 feet above the ground. With very little air movement, high temperature, high humidity, and very few clouds, a few days each year are almost unbearable.

Environmental studies reported herein were conducted each summer between June 21 and September 27. Weather records were kept every summer, and table 1 shows the average maximum, minimum, and mean air temperatures and relative humidities for the test period of 1947 to 1956 inclusive.

Although the Imperial Valley and surrounding areas have a humid condition during part of the summer, the humidity is still lower than that of the states around the Gulf of Mexico. Figure 3 shows average diurnal air temperatures and relative humidity at the Imperial Valley Field Station, California, Baton Rouge, Louisiana, and Corpus Christi, Texas, from July 6 to September 14, 1955. Air temperatures at the Field Station averaged 102° F during the heat of the day, while the relative humidity was 20 per cent. At Corpus Christi and Baton Rouge air temperatures average around 87° F and relative humidity about 60 per cent during the middle of the day.

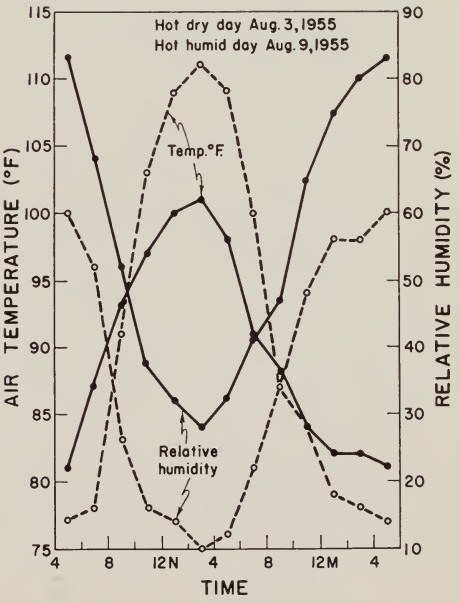


Fig. 2. Diurnal air temperature and relative humidity for a hot, dry day and a hot, humid day at the Imperial Valley Field Station.

Table 1—Weather During Feeding Periods

Data for Imperial Valley Field Station During Test Periods, 1947 to 1956 Inclusive

Year	Period of feeding trial	Air temperature (F.)			Air relative humidity (%)			
		Ave. Max.	Ave. Min.	Mean	Ave. Max.	Ave. Min.	Noon	Mean*
1947	July 23 to September 15	105.7	74.7	90.2	67	26	34	46
1948	July 28 to September 20	108.1	74.7	91.4	55	17	25	33
1949	July 12 to September 16	104.3	73.4	88.9	71	24	31	44
1950†	June 21 to September 9	105.1	74.8	89.9	76	28	39	47
1951	July 3 to September 27	103.7	71.8	87.7	78	29	36	50
1952	July 2 to September 11	106.7	77.7	91.8	66	26	26	40
1953	June 30 to September 22	105.5	77.1	91.3	61	19	24	36
1954	June 24 to September 16	103.6	76.4	90.0	67	19	28	39
1955	July 6 to September 14	103.2	78.3	90.3	80	23	29	46
1956	June 27 to September 5	102.4	74.2	88.3	68	17	22	36

* The mean relative humidity is the average of all 2-hr. readings throughout the period.
† One group was fed from June 14–September 5 and weather data are almost the same as those shown.

Tallahassee, Florida, is about the same as Baton Rouge, Louisiana; but the data are not included in figure 3. As a further comparison of the difference between a "hot dry" and a "warm humid" climate, figure 4 shows the mean daily air temperature for the Imperial Valley Field Station, California, Corpus Christi, Texas, Baton Rouge, Louisiana, and Tallahassee, Florida. Mean daily air temperatures are about 90° F for the California Station and between 80° and 85° F for the other three stations.

Rainfall during June, July, August, and September is rather heavy in the Gulf Coast States, averaging 11 inches for Corpus Christi, 20 inches for Baton Rouge, 26 inches for Tallahassee, and only 0.7 inch for El Centro. Air movement in these Gulf Coast States varies some, but the average ranges between 5 and 12 mph, while in the Imperial Valley it averages around 2.5 mph for the summer months. Air movement at the station was taken 3 feet above the ground.

Climatic conditions are different in these four areas, but all have somewhat similar problems in livestock production because of their summer heat.

Solar and Sky Radiation

As will be discussed later (page 18), a large part of the heat load on an animal is due to radiation from its surround. The solar and sky radiation influences, directly or indirectly, the thermal environment of entire areas and is dependent, at any particular time, upon altitude, latitude, cloud cover, and air moisture, gas, and dust content.

The United States Weather Bureau has for many years used Eppley pyrheliometers to observe solar and diffuse sky radiation throughout the country. These measurements indicate a higher than average radiation intensity in the Imperial Valley as compared with other sections of the country at the same latitude. For instance, the July, 1955, isolines for this area show a daily average solar radiation of about 600 langleys, whereas the southeastern part of the United States averaged about 500 langleys.

Much of this difference can be attributed to the greater cloud cover in the

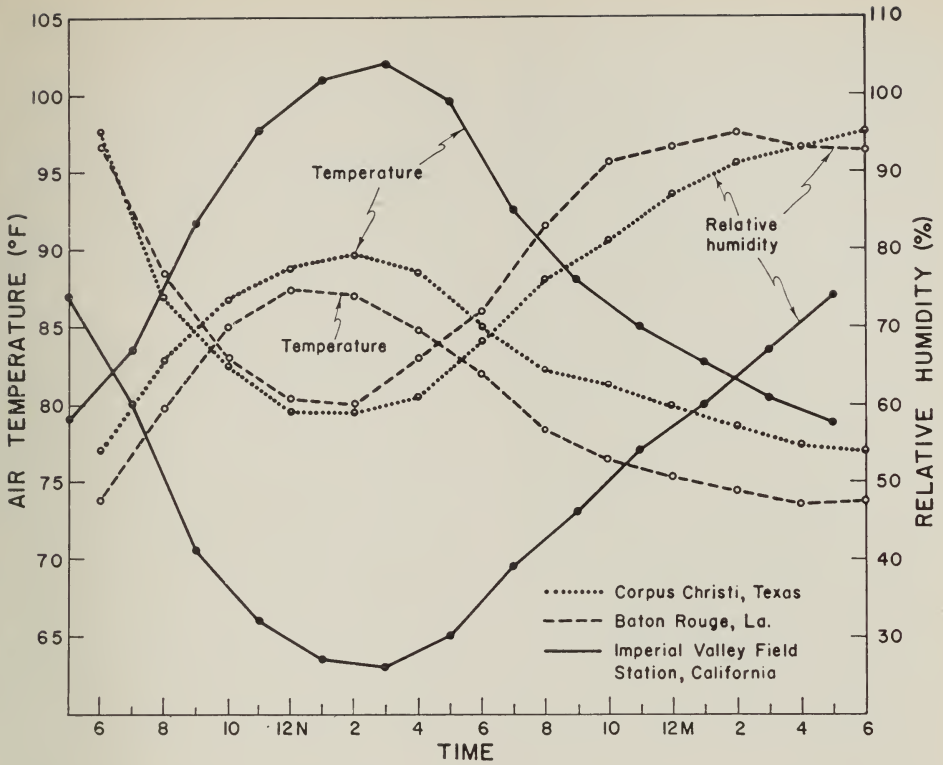


Fig. 3. Average diurnal air temperature and relative humidity at four points south of the 75°F isotherm from July 6 to September 14, 1955. (Out-of-State data from the U. S. Department of Commerce Weather Bureau.)

more easterly sections. The average cloudiness during June, July, August, and September, is, on the 0 to 10 basis, 4.2 for Corpus Christi, Texas, 5.2 at New Orleans, Louisiana, 5.3 at Apalachicola, Florida, but at Yuma, Arizona, 50 miles east of El Centro, California, only 1.3 (U. S. Department of Commerce, 1956). No continuous records of solar and sky radiation are available for the Imperial Valley, but observations by the authors with the portable instruments

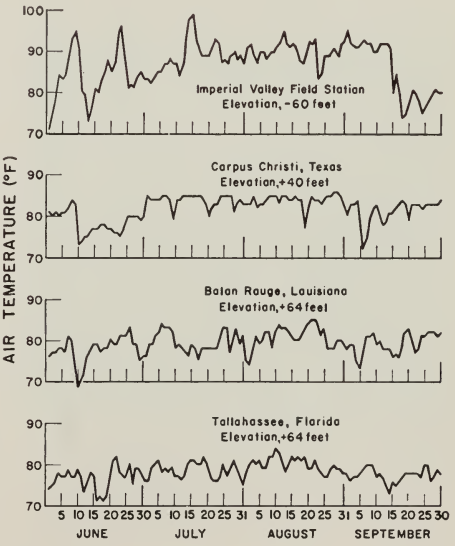


Fig. 4. Mean daily air temperature during June, July, August, and September at four points south of the 75°F isotherm. (Out-of-state data from the U. S. Department of Commerce Weather Bureau.)

described on page 17 indicate many days during July and August with noon half-space radiation intensities on a horizontal surface of 425 to 475 Btu/hr. sq. ft. as measured by a total energy radiometer and of about 300 Btu/hr. sq. ft. as measured by an Eppley pyhrheliometer.

Experimental procedures and instruments

The results of a good many feeding trials are reported in this bulletin, and to eliminate repetition the standards used are discussed in this section.

All animal weights, unless otherwise noted, are after a 10-hour stand in a dry corral without feed or water. In most cases weights were taken every 28 days.

The wooden corral pens were 50 x 50 feet enclosed by a 6-foot fence constructed of four 2 x 10-inch planks. Each pen had a hay or aluminum shade 10 feet above ground. All wire pens were made of ordinary fence wire and all have hay-covered shades at least 10 feet high.

Water consumption was measured by calibrated water meters on the water inlets. Since the accuracy of these meters is highest when a full stream of water is flowing through them, a float and micro-switch were arranged with a solenoid water valve so that full flow was obtained whenever the water level in the tank dropped 1 inch. The water meters were read at least once a day; and on some days hourly observations were made. Pen recorders kept a continuous record of the temperature of the water near the top of the tanks. Not all lots had these recorders. Feeding was by hand and all lots were fed twice a day.

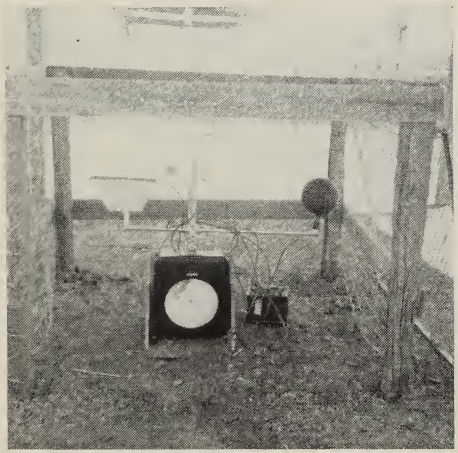


Fig. 5. Portable "spot" climate recorder. The 4-pen clock-operated recorder provides 24-hour records of air and ground temperatures, globe-thermometer temperature, and wind velocity.

The instruments used for defining the environment were for the most part portable, so that they could be moved from pen to pen, or from pen to open area. A continuous record of air temperature and relative humidity was, however, obtained by a Friez hygrothermograph located in a standard Weather Bureau shelter about 600 feet from the main corrals. In recent years some wind-velocity data have also been collected at this location. The Friez cup-type anemometer used for measuring wind velocity was only 3 feet above the ground, a little more than half the height of a standing cow. As new instruments became available they were used in the project, so that the same types of instruments were not necessarily used throughout the period covered by this report.

The portable instruments were of two general types: those for measuring the air temperature and velocity, and those for measuring radiation.

Air temperature and velocity: Small portable weather stations were used where a continuous record of air temperature and velocity was required at a particular location over periods of several weeks or months. These have been described in detail by Schultz and Brooks (1956). A 4-pen clock-operated recorder allowed 24-hour or 7-day records to be obtained. One pen recorded air temperature as sensed by a fluid-filled capillary tube, another ground temperature, and a third globe-thermometer temperature. The latter was 8 inches in diameter. The fourth pen was used to record impulses from a Friez cup-type

anemometer, at the rate of one impulse for each 1/12 mile. A view of one of the portable or "spot" climate recorders is shown in figure 5.

Other devices used to measure air temperature were small copper-constantan thermocouples shielded with metal cylinders, mercury thermometers, etc. The Alnor Velometer, a vane-type anemometer, was also used to indicate air velocities.

Radiation: Since such a large part of the experiment was related to protecting the animals from solar radiation, special attention was given to radiation measuring instruments. To measure total spherical radiation (both sky and ground), globe thermometers—either 6 or 8 inches in diameter—were used. These give, by means of the internal temperature of a black, hollow copper sphere, the result of the combined effects of air temperature, spherical radiation, and air velocity. By calculation, the mean radiant temperature of the entire surround may then be obtained with varying accuracy, depending upon the rates at which the climatic factors—air temperature, radiation, and air velocity—are changing. A complete discussion of this instrument has been given by Bond and Kelly (1955).

Recently the "spherical radiometer" was developed for this project and has been used especially for checking the mean radiant temperatures as measured by globe thermometers. This instrument consists of two 2-inch-diameter spheres, one of polished silver, the other black. The spheres contain heating elements by which the sphere temperatures can be maintained equal and convection losses compensated for. The current used is a measure of the spherical radiation (Dunkle and Gier, 1954).

To measure half-space radiation, or the energy falling on a flat horizontal surface, use was made of the total energy plate radiometers developed by the Illumination Laboratory, University of California, Berkeley. (See Gier and Dunkle, 1951, for complete description). The sensing element of this instrument is a thermopile, whose electromotive force was indicated by a Leeds and Northrup No. 8662 semi-precision potentiometer in field observations, and by a Brown recording electronic potentiometer in stationary use. A view of the instrument on its tripod in the field is shown in figure 6. This instrument is designed to measure all radiant energy falling upon a horizontal surface, including both long and short wave-lengths. There is no cover of glass or other material to act as a filter, and the receiving surface has a high absorptivity for all wave-lengths.

Another instrument sometimes used to measure half-space radiation was the Eppley pyrheliometer, described by Lee (1953). Because its sensing element is covered with glass, it measures only the solar and diffuse energy, and screens out most of the long-wave atmospheric radiation.

The "Solarimeter" as developed by Gier and Dunkle was used at times for measuring half-space radiation (solar and diffuse), its response being similar to the Eppley pyrheliometer. It consists

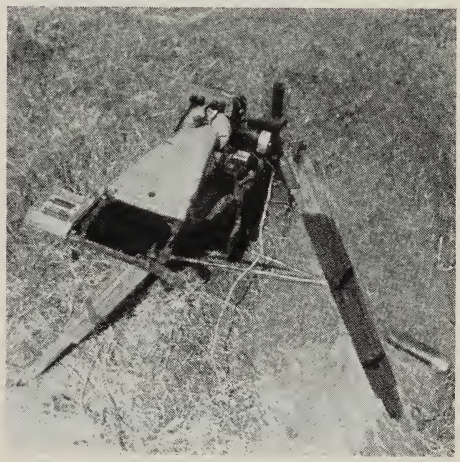


Fig. 6. Flat-plate radiometer and solarimeter mounted for portable field use.

of two thermopiles encased in a plastic cover, one painted white, the other black (figure 6).

Brooks (1951) has stated that the solar and diffuse radiation amounts to about 60 per cent of the total sky radiation as measured by the total energy radiometer. Since an animal's surface absorbs both short and long-wave energy, it seems that the total energy radiometer would be a better indicator of radiation heat load upon an animal than would an instrument of the type of the Eppley pyrheliometer.

Where it was desired to determine the radiosity of a smaller area or object, one of two instruments was used—either a Gier directional radiometer or a Hardy dermal radiometer. These have been described in detail by Kelly, Bond, and Lorenzen (1949) and by Hardy (1934). The sensing elements of both instruments are blackened thermopiles. The Gier radiometer has a cone opening of 16°, the Hardy dermal radiometer one of 12°. They were used to obtain radiosity and temperature of cattle surfaces, shade and corral materials, ground cover, and effective sky temperatures in selected locations.

The Experiments

Studies of different materials and techniques for cooling animals

Providing a comfortable environment for livestock during the hot summer can be considered as a problem in heat transfer. There are four avenues of heat transfer available to the animal for cooling itself: *Radiation, convection, evaporation,* and *conduction.* These four methods do not operate alone, and their effects on cattle are always changing. To study one of these methods of heat transfer by itself is impossible, since cattle in the open are also affected by the other three means of heat transfer at the same time. Since all four methods are operating together most of the time, this study has been broken down into five categories: *cattle shades, water as a cooling agent, air movement, radiation of an animal's surrounding,* and *rations for high summer temperatures.*

CATTLE SHADES

Shades will reduce the radiation heat load from the sun and sky by more than 50 per cent. There are a number of factors that cause the effectiveness of any given shade to vary. For a more detailed discussion of these factors and their effect on thermal design of shades see Kelly, Bond, and Ittner (1950).

An animal in the sun receives radiant energy from three sources: (a) sun and sky, (b) unshaded ground, and (c) horizon, actually a band extending about 10 degrees above the horizon which is separated from the remainder of the hemisphere in calculations because it radiates at a greater rate as a result of back radiation from moisture in the heated air near the ground.

On a typical August day at the Imperial Valley Field Station the total radiant heat load on an animal in the sun was 244 Btu per hour ft.^{2} (of animal surface), as determined from black-globe thermometer readings. Under a shade the radiant heat load was 167 Btu per hour ft.^{2} Shade reduces radiant heat load from the sun and sky, and substitutes shaded area for part of the hot

ground, but it adds a new source of energy, the shade material itself. In this instance the total effect was nevertheless a reduction of the radiant heat load on the animal, from 244 to 167 Btu per hour ft.^{2} of animal surface. This is equivalent to reducing the mean radiant temperature* of the animal's surround from 153° to 98° F.

Shade Material

Several different types of shade material and two heights of shade—7 feet and 12 feet—were tested during the summers of 1947, 1948, and 1949. In 1947 the weighing facilities and the number of animals involved in the tests were inadequate, but a considerable number of radiation readings were taken throughout the summer. Four shades were tested during the summer of 1947; each was 16 × 24 feet and 10 feet high at the eaves. The roofs are gable with about an 18-inch rise. A brief description of each follows:

1. Wood slat shade. The roof is constructed of 1 × 10 inch boards spaced 1 inch apart. The cracks run east and west. The floor is dirt.

2. Hay-covered shade. The roof is about a 6-inch layer of coarse hay held in place between two layers of woven-wire fencing. The floor under the shade is concrete.

3. Aluminum shade. The roof is commercial 5-V Crimp aluminum sheets. The floor is concrete and has a 2-inch drain in one corner. Overhead, down the center of the shade, are several spray heads which may be used to produce a fine spray under the shade. Although this shade was equipped with the sprinklers, it was tested without the sprinklers with the radiation instruments.

4. Galvanized iron shade. The roof is old, corroded corrugated galvanized sheet iron, and the floor is dirt.

In June, 1947, before animals were available for the experiment, the intensity of radiation under each shade was compared with that from the unshaded sky and sun by means of a flat-plate radiometer. The instrument was held 3 feet above the ground, and readings were made on both the upper and lower hemispheres. The observations covered a period of several hours during the hottest part of the day. When measuring the radiation under a shade, the instrument was held at the center of the shadow. From 10 A.M. to 2 P.M. the radiation from the upper hemisphere was reduced 65 per cent by the solid shades (galvanized iron, aluminum, and hay covered), and 55 per cent by the wood-slat shade. This agrees well with the findings of workers in Africa (Reinerschmid, 1943). There was a slight difference in the amount of energy reaching the flat-plate under the various shades. For instance, at 12 noon, when the air temperature was 99° F, the energy incident on the instrument under the hay shade was 181 Btu per hour/ft.^{2}; under the aluminum shade, 190; under the galvanized shade 193; and under the wood slat shade, 223. At this time the total solar and sky radiation, including incoming long-wave atmosphere radiation, amounted to 527 Btu per hour/ft.^{2}. In other words, the hay covered shade cut off 1.7 per cent more of the solar energy than did the aluminum shade, 2.3 per cent more than the galvanized iron, and 8 per cent more than the wood slat shade.

It was found that shades also reduced the radiation from the lower hemisphere, or the ground, although not as much. At 12 noon, when the ground radiation in the sun, amounted to 242 Btu per hour/ft.^{2}, the ground radiation under the solid shades averaged about 173 Btu per hour/ft.^{2}, a reduction of 28 per cent. Again there was a slight difference noted in

* Mean radiant temperature: that temperature of a uniform enclosure (usually designated black to eliminate reflection) with which a body would exchange the same amount of energy by radiation as in the actual environment.

effect of the various shades. The hay and aluminum shades reduced the ground radiation 28 per cent, the galvanized iron 27 per cent, and the wood-slat shade 22 per cent. It should be noted that the sprays were not in operation under the aluminum shade at the time of these observations, and that the ground or floor under all shades was dry. Some of the differences in ground radiation, however, may be attributed to differences in floor material.

In August quantitative measurements of radiation from the zenith and from several angles below the zenith, as well as from several angles in the lower hemisphere, were made with a Hardy dermal radiometer. This instrument included in its view an angle of only 12°, rather than the entire hemisphere, as did the flat-plate radiometer. The results of the "scanning" of the hemispheres are shown in figure 7 for each of the shades. As with the flat-plate radiometer, the instrument was held about 3 feet above the ground, at the center of the shadow.

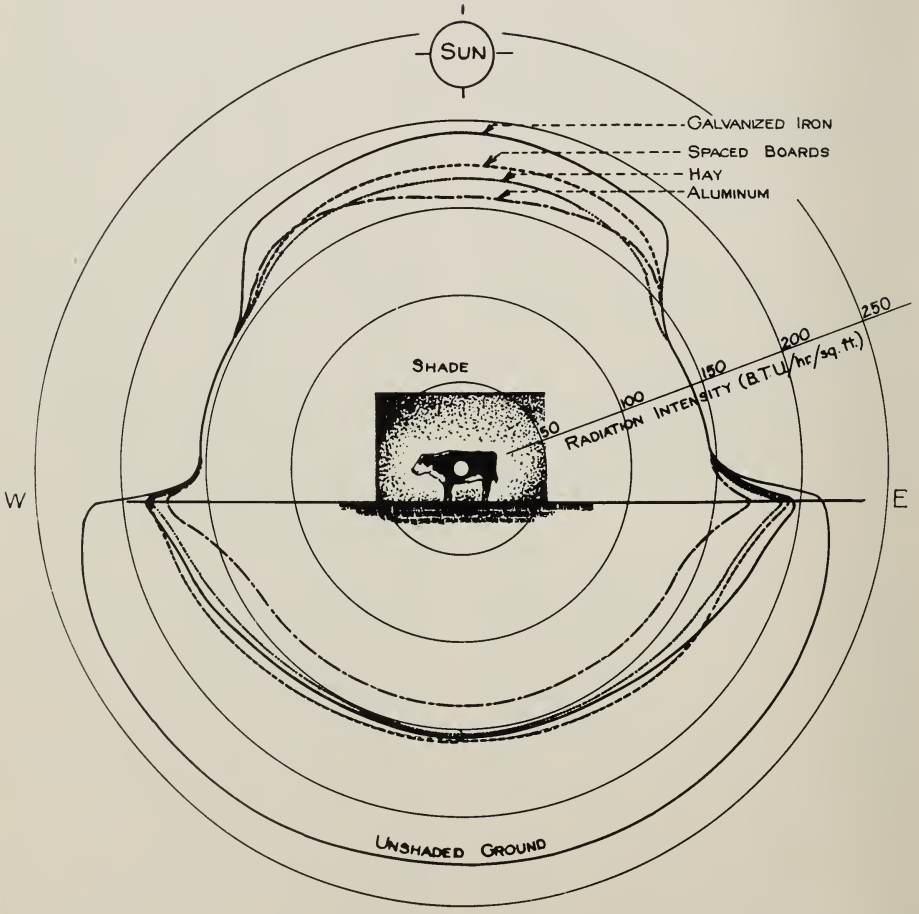


Fig. 7. Radiation from shade, unshaded sky, and ground at center of shadow, at noon, under four shades at the Imperial Valley Field Station. Observations made August 22, 1947.

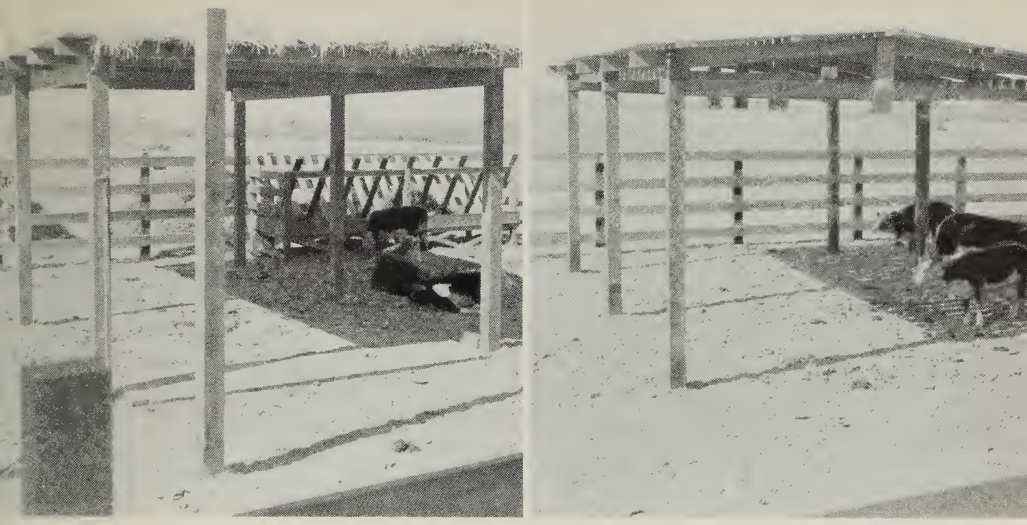


Fig. 8. View of the hay-covered shade (left) and the slatted-wood shade (right).

The air temperature was 95° F. The sprays under the aluminum shade were cut off, but the concrete floor was wet.

As shown by figure 7, this instrument indicated a slightly different order of efficiency of the several shades in cutting off the solar radiation, namely, (a) aluminum, (b) hay, (c) wood slat, and (d) galvanized iron. The heifers under the hay-covered shade and wood-slat shade are shown in figure 8.

While the animal standing in the shadow of a shade is protected from the direct rays of the sun, it is still receiving and giving energy to and from the surroundings, depending on its surface temperature and emissivity, and the temperature and emissivity of the surroundings. The roof of the shade is usually above the air temperature, during the daytime. Observations in August, 1947, indicated that at midday, at times when the air temperature was about 100° F, the temperature of the underside of the El Centro shades (the side radiating to the animals standing in its shadow) averaged for the galvanized iron, 26° above air temperature; for the aluminum shade, 10°; for the wood shade, 9°; and for the hay shade, 5°. The original data are given in table 2 along with the emissive power as obtained by the Hardy radiometer.

The value of each shade material in cutting off solar and sky radiation was also determined by the reactions of cattle sheltered under them. Between July 23 and September 15, 1947, three Hereford heifers were placed in the pens surrounding each of the four experimental shades, and their physiological reactions, feed consumption, and weight gains were observed. They were fed fair quality alfalfa hay, a little cottonseed meal, salt, and water. Although the length of time was short, the number of animals small, and most differences between pens not statistically significant, almost all differences followed the same pattern; that is, those animals under the hay and aluminum shades appeared cooler and more comfortable than those under the wood-slat and galvanized iron shades. The normal body temperature of a cow is between 101° and 102°, while the comfort zone for respiration rate is between 20 and 50 breaths per minute. Between July 23 and September 3, with a mean air temperature of about 90° F, 31 sets of body temperatures were taken on these

heifers. Unfortunately, there was a wild heifer under the galvanized iron shade, and only a few body temperatures were taken on this group. Body temperature averages were as follows: hay roof, 103.0° F; aluminum roof, 103.3° F; and wood slat roof, 103.5° F. The difference in respiration rates of the four pens was negligible, all averaging about 90 per minute.

The average rate of gain for all animals was poor, being 0.48 pound per day for the 55-day test period, but the animals under the hay and aluminum shades again did a little better than those under the other two shades. Feed consumption followed the same pattern as the rates of gain. Salt consumption was normal.

Cooling Shade Surfaces by Evaporation

Animals may lose heat by radiation to the surround, as well as to the air by convection and evaporation, when the radiosity of the surroundings is less than that of the animal's surface. In 1948, water was used to cool the surface of two shades in order to lower their temperature (by evaporation), which thereby lowered that portion of the radiant temperature of the surround. Both shades had double roofs, spaced about 3 feet apart. In the first shade, a sub-roof of burlap sacks was kept wet by four sprinklers spaced evenly above it. Surplus water dripped from the burlap to a drained concrete floor, usually wetting the cattle somewhat in the process. The burlap sub-roof (21×21 ft. in size, compared with 16×24 ft. for the upper aluminum roof) was 7 feet above the pavement (fig. 9).

The second shade had a water-cooled sub-roof of galvanized iron (16×24 ft.), sloping to one side to carry surplus water to a drain, leaving the floor dry. The upper roof was of hay and of the same size. The plain galvanized iron shade mentioned previously was used as a check for these two cooled shades.

In August, 1948, comparisons were made on the basis of (a) air temperature beneath the shades, (b) temperature of roof surfaces next to the cattle, (c) temperature of ground beneath the shades, and (d) amount of solar, sky, and ground radiation cut off by the shades. The average figures from a series of readings on a typical day, which had a maximum air temperature of 109° F,

Table 2—Temperature and emissive power of under surfaces of shades covered with hay, wood, galvanized iron, and aluminum, at Imperial Valley Field Station

Date (1947)	Time	Air temp., deg. F.	Hay covered		Wood covered		Galv. iron covered		Aluminum covered	
			Temp., deg. F.	E*	Temp., deg. F.	E*	Temp., deg. F.	E*	Temp., deg. F.	E*
June 25	1:35 p.m.	100	101	...	104	...	122	...	112	...
	2:30 p.m.	98	104	...	106	...	120	...	...	...
Aug. 19	11:10 a.m.	102	107	174	112	190	139	194	127	172
	2:40 p.m.	108	114	160	115	181	125	180	124	166
Aug. 22	12:00 noon	95	101	167	110	174	128	187	118	156

* Emissive power (Btu/hr/sq. ft.) as determined by Hardy radiometer.
NOTE: Air temperature obtained by No. 30 BS gage shielded copper constantan thermocouple and surface temperatures by touch thermocouple of same size wire.

Table 3—Average environmental conditions under the three shades on August 6, 1948. Between 11:00 A.M. and 1:00 P.M.

Comparison	Galvanized iron check shade	Burlap roof cooled by sprinklers	Galvanized iron cooled by sprinklers
Average outside air temperature (°F.)	103.5	103.5	103.5
Air temperature under shade (°F.)	104.0	101.5	101.5
Temperature of underside of roof (°F.)	127.5	89.0	92.0
Temperature of ground in shadow (°F.)	107.5	97.2	100.0
Radiation from sun and sky cut off by shade (%)	56	61	62
Lowering of ground radiation by shade (%)	27	37	31

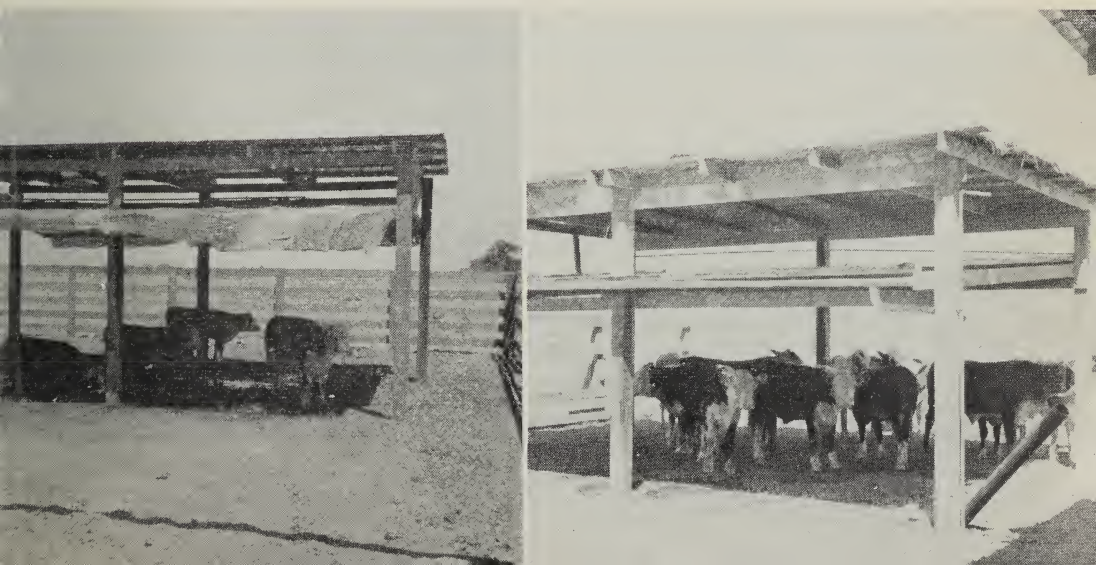
and a minimum of 84° F, are given in table 3.

The temperatures of the undersides of the roof surfaces were markedly different. The wet, shielded, galvanized iron shade at times was 36° cooler, and the wet burlap was 45° cooler than the uncooled galvanized iron roof. Cooling the sub-roof had little effect upon air temperature. Beneath both cooled shades the air averaged about 2° cooler than outside. The check shade showed no lowering of air temperature.

The wet pavement beneath the burlap-covered shade was as much as 10° lower than the ground below the check shade. The ground beneath the cooled galvanized iron shade was 3° cooler than that under the check shade on the average, and 7° cooler during the hottest part of the day.

This lowering of the radiosity of the surround with shades will decrease the radiant-heat load on the animals from 176 Btu per hr. per sq. ft. of animal surface with the uncooled check shade, to 165 with the wetted galvanized iron shade, and to 157 with the wetted burlap shade. In other words, a 700-pound steer with a surface area of about 42 sq. ft. exposed to radiation would receive 462 Btu per hr. less under the wetted galvanized iron shade than under uncooled surface shade, and 798 Btu per hr. less under

Fig. 9. Shades with surfaces cooled by evaporation of water used in 1948 tests. Shade at left has burlap sub-roof; right hand shade galvanized iron sub-roof.



the wetted burlap shade. This calculation is based upon observations made at 11:30 A.M., September 1, 1948, when the ambient air temperature was 101° F.

The effect of the two cooled shades and the galvanized iron check shade was evaluated by a 54-day feeding trial. On July 28, 17 good quality Hereford steers and 6 good Braford steers were divided among the three pens. Throughout the test period these animals were fed all the good alfalfa hay they would consume, and during the last 27 days they received, in addition, 1 pound of barley per head daily.

The data on weights and gains are shown in table 4. Two Brafords were assigned to each shade. All gained at approximately the same rate. Their greater heat tolerance apparently made them less sensitive to differences in types of shades. Inclusion of these animals made it impossible to ascertain the feed consumption of the Herefords. The weight-increase data in the table are for the Herefords only. During the test, one Hereford in the pen with the galvanized iron roof died from an undetermined cause, and this animal is not included in the results. The Herefords under the hay and galvanized iron roofs gained at the most rapid rate, 0.89 pound per head daily, and those under the plain galvanized iron shade gained the least, 0.69 pound per head daily. The animals under the aluminum and burlap roofs made daily gains of 0.80 pound. However, one animal under the wet burlap shade was sick during most of the experiment, and if he is eliminated from the calculations, the rate of gain would be 0.90 pound.

Drip from the wet burlap roof kept the animals damp, and they seemed to be more comfortable than the animals in the other pens. The concrete floor under this shade had to be cleaned several times a week and sanitation was a problem. The animals under the plain galvanized iron shade suffered the most, as evidenced by increased panting, driveling, and smaller gains.

On a particularly hot day, when the air temperature at 3:00 P.M. was 118° F and the relative humidity 15 per cent, the average respiration rates per minute under the three shades were: galvanized iron, 116; double roof with galvanized iron, 105; and double roof with burlap, 80. Brafords usually had about as many respirations per minute as the Herefords, but their breathing was much shallower. On this very hot day the Brafords averaged a few respirations more per minute than the Herefords, but their degree of suffering was much less.

All the measurements taken during this test show the two wetted shades to provide a cooler environment for the

Table 4—Comparison of weights and gains of Hereford steers with three different types of shade materials

(July 28–September 20, 1948)

Type of shade	Number of Herefords	Average* initial wt. July 28 (lb.)	Average* final wt. Sept. 20 (lb.)	Average daily gain (lb.)	Feed/100† lbs. gain (lb.)
Galvanized iron roof	5	430	467	0.69	1230
Aluminum and burlap roof	6	429	472	0.80	1266
Hay and galvanized iron roof	5‡	420	468	0.89	1091

* Average weight and gains are only for the Herefords since there was no significant difference between the Brafords.
† Feed per 100 pounds of gain includes feed eaten by the Brafords.
‡ One Hereford died.

steers. The steers under these two shades were more comfortable, gained about 0.20 pound more than the check pen, had lower respiration rates, and did less driveling. Nevertheless, the increases in gain do not seem to be enough to compensate for the higher cost of constructing double-roofed shades and the extra work of keeping the pens sanitary.

High and Low Shades, 1948–1949

At another corral were two shades, identical except for height; one was 7 feet high to the underside of the roof, while the other was 12 feet high. Both were 18 × 36 feet and were covered with hay supported by wire (fig. 10). A group of animals on pasture had access to these shades and showed a decided preference for the 12-foot one. Measurements with a flat-plate radiometer showed that the high shade cut off 64 per cent of the total solar and sky radiation at noon as compared to 61 per cent for the low shade.

In 1949, the experiment with the low and high shades was repeated, but the corral was rebuilt so that the exit to the pasture was the same distance from each shade, and a water tank placed in line with each. A manger for hay was set up between the two, so that it did not cast a shadow in either of the shaded areas. Thus, the two shades were equally convenient. Eight Hereford steers averaging 650 pounds used these shades. They were fed about 13 pounds of alfalfa hay per head daily along with the alfalfa pasture, and gained 1.57 pounds per head daily during the test period (July 12–September 16). The high shade was used almost exclusively.

Observations in 1948 under several experimental shades showed that the type of shade has very little effect on the air temperature under the shelter, unless water is evaporated into the air from sprays or from urine and feces. A more complete test was made in 1949 with the 7-foot and 12-foot shades. Using a 16-point recording potentiometer, a continuous record of air temperature at several levels was obtained under these two hay-covered shades for 48 hours. Thermocouples of 30-gauge copper-constantan wire were supported from the roofs at heights of 1, 3, and 6 feet under the low shade and at 1, 3, 6, 9, and 11 feet under the high shade. The supports were moved hourly so that the bottom thermocouple was always close to the center of the shadow. At night all junctions were left directly under the center of the shade. While there was some evidence of stratification at higher elevations, at the 1- and 3-foot levels, occupied by the animals, there was little difference between the two shades. Most of the benefit, as far as animal comfort is concerned, should be ascribed to a lowering of the radiation heat load.

Fig. 10. Hay-covered shades, one 7 feet and the other 12 feet high to the underside of the roof.

Louver Shade

A louver shade was also tested in 1949. The louvers were set at such an angle that a solid shadow was cast on the ground but allowed almost total exposure of the animals to the colder north sky (fig. 11). The angle and spacing of the slats (1 × 10-inch boards) were calculated for the latitude of El Centro at noon of the longest day. The over-all size of the shade was 13½ × 22 feet. At first this shade was 6 feet above the ground, but later it was raised to 9 feet. This

shade was compared with the galvanized iron shade and the hay-covered shade with a sub-roof of galvanized iron, but no water was used for cooling.

Animal preference was used as an indicator of the effectiveness of these three shades. The test animals included eight Hereford and eight Braford steers, averaging about 650 pounds each. They had access to pasture and, in addition, were fed an average of 6.4 pounds of good alfalfa per head daily. The Herefords made an average daily gain during the 66-day test period (July 12 to September 16) of 1.20 pounds, while the Brafords averaged 2.13 pounds.

The cattle came in from pasture about 7 A.M. and went out again between 4 and 5 P.M. Gates of the corrals were left open, giving all the animals free choice of the shades. Their preferred resting place was the double-roofed shade. The galvanized iron shade was never used and the louvered shade only occasionally, although both were more conveniently located relative to feed. About halfway through the test, the louvered shade was raised from 6 to 9 feet, but the preference of the steers remained the same.

A comparison of the energy incident on a flat surface was made by means of a hemispherical radiometer at noon on August 24 when the air temperature was 106° F. The double-roof shade cut out 58 per cent of solar and sky radiation at the center of the shadow; the galvanized iron shade, 54 per cent; and the louvered shade, 53 per cent. The south end of the louvered shade cut off even less energy (51 per cent). By the use of a directional radiometer, traversing from the north horizon through the zenith down to the south horizon, it was found that the high-intensity radiation was energy reflected from the top side of the louvers down onto the steers. A person standing under the shade could feel the concentration of energy on the face and body from the north side. Raising the shade to 9 feet gave the same effect, although intensity was less at cow level.

Fig. 11. Louver shade.

Trees for Shade

Trees have been suggested as providing the "ideal" shade. Because of their irregular shape, their comparative value is difficult to measure. A limited number of observations at Davis indicate that their radiosity may be somewhat less than for a flat aluminum shade. A large black walnut tree averaged 138 Btu per hr. sq. ft. when viewed from the shadow beneath it; a smaller catalpa tree averaged 141 Btu, and an aluminum shade, 170 Btu. At this time the air temperature was 83° F, with a slight breeze. One distinct advantage of trees is the fact that, because of their thickness of mass of leaves, their shadow is always larger than the vertical projected area, giving a larger low-temperature ground area with a given exposure to cool sky than is possible with a thin shade. Disadvantages of trees are that in many cases the shadow is not solid because of openings between leaves, and that they do not fit into practical farming practice where it is desired to rotate pastures frequently.

Painted Shade Materials

Certain materials, such as white paint, are highly reflective (low absorptivity) to short-wavelength radiation and are

Fig. 12. Three $8 \times 8 \times 4$-feet-high test shades set up over a dirt field. Note black-globe thermometers at center of each shadow and in sun.

very good emitters (high emissivity) of long-wave radiation at their normally low temperatures. In the study described below, white-painted aluminum sheets were as much as 15° cooler than unpainted aluminum sheets when exposed to the sun. White-painted galvanized iron sheets were as much as 50° cooler than unpainted ones. While the characteristics of the top surface greatly influence the temperature of the shade material, it is the emissivity of the bottom surface that influences the quantity of energy, due to this temperature, that will be emitted to the animal. The reflectivity of the bottom surface determines the quantity of incident energy, from the ground, that will be reflected back down to the animal.

To study the thermal effects of changes in radiation characteristics induced on the surfaces of various shade materials by painting, field tests of several materials were conducted during the summers of 1952 and 1953. Three flat, portable shade frames, $8 \times 8 \times 4$ feet high, were covered with the materials tested. The frames were collapsible so that they could be easily moved (fig. 12). One frame was always covered with plain corrugated embossed aluminum roofing to serve as a check shade.

The real thermal comparison of two shades should be based on the relative comfort of animals under them. To obtain such comparisons, one 6-inch black-globe thermometer was placed under each of three shades and kept in the center of the shadow. A fourth globe was placed in the sun to serve as a basis for comparison. The temperatures of the shade materials were obtained with thermocouples attached to the under-surface of the shades. Temperatures of both the globes and the thermocouples were continuously recorded by a 16-point recording potentiometer. The quantity of radiant energy from the shade surface and from different parts of the surround was measured with a Hardy radiometer.

The upper left-hand section of figure 13 shows the radiant heat load on the globes under three shades covered with corrugated embossed aluminum roofing. One was left unpainted. Two coats of Fuller's Myratic No. 1520 white paint were applied to the top surface of the remaining two, and the bottom surface of one of these was painted with two coats of Fuller's Myratic No. 1518 velvet black paint. The lower set of curves shows the surface temperatures of these three shades.

White paint and the unpainted alu-

minum sheet reflect about the same amount of solar energy (about 75 per cent), but the emissivity of the white paint at ordinary shade material temperature, is much greater (about 0.89) than that of the unpainted aluminum (0.11 to 0.20). The white-painted surface consequently maintained a lower temperature because of better radiation exchange with the cold sky. Since the radiation characteristics of the bottom surfaces were identical, the radiant heat load under the white-painted shade was considerably less.

The surface temperature of the third shade, painted white on top and black underneath, was about the same as that of the white-top shade, and yet the radiant heat load under it was as much as 13 Btu per hr. ft.^{2} less. Since the upper-surface radiation characteristics of these two were the same (white paint) the differences must be attributed to a reduction of reflected energy under the black-painted shade. The undesirable effect (greater emission by the black surface) was less than the desirable effect (reduced reflection of incident energy). The black surface absorbed more radiation from the unshaded ground than did the unpainted surface, but at the same time it lost heat at a greater rate by radiation to the cool shadow. Furthermore, convection cooling would tend to prevent an excessive temperature rise of the black surface.

The surface temperatures of the painted shades were at times 15° lower than that of the unpainted shade. The radiant heat load under the white and black shade was as much as 18 Btu per hr. ft.^{2} lower than under the unpainted shade.

Hay has invariably proved "cooler"

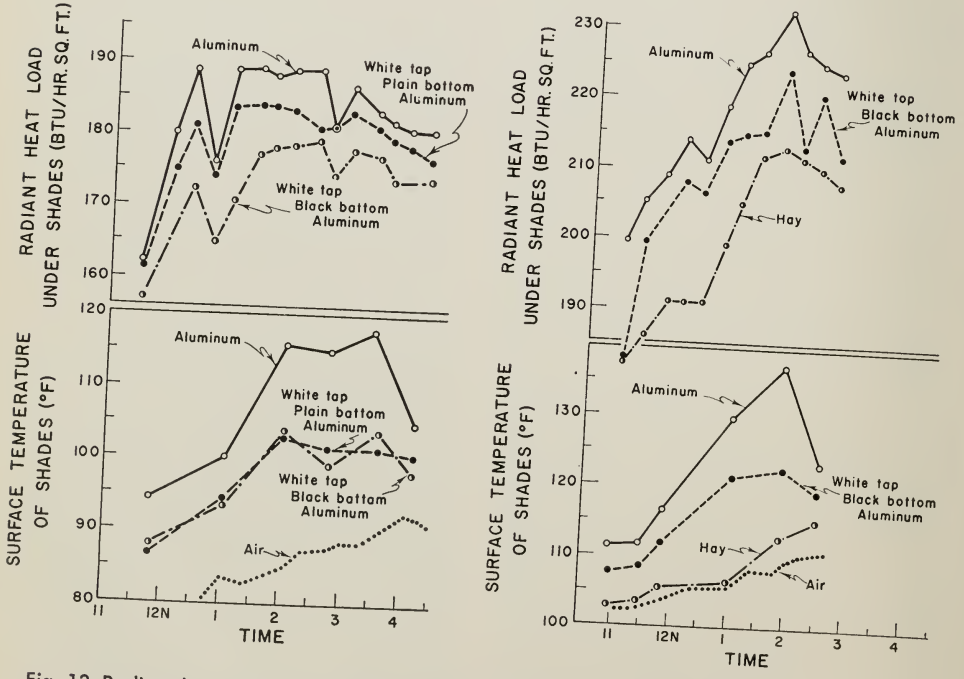


Fig. 13. Radiant heat loads under 8 × 8 × 4-foot shades over dirt. Radiant heat load under each shade was determined from globe thermometer at the center of shadow. Surface temperatures of the shade materials are also shown.

than most other shade materials. One of the shades was covered with a 4-inch layer of hay, and results were compared with the unpainted and the white and black aluminum shades. The curves for this test are shown in the right-hand section of figure 13. The radiant heat load under the hay shade was much lower than that under the other two shades. Here, the hay temperature (bottom surface) remained very close to that of the air, and as much as 25° lower than the surface temperature of the plain aluminum shade. The very uneven character of the hay surface evidently acts as a black surface and absorbs most of the irradiation on it from the hot ground, thereby reducing the energy reflected back down to the animal. We do not know what the surface convection coefficient for the hay is, but, because of the uneven character of the surface, it is probably very high. The hay presumably lost much of its heat to the air by convection. Also, because of the insulating value of the 4-inch layer of hay, the bottom surface did not receive much heat from the top surface by conduction. Although hay has excellent thermal properties, it does have limitations as a shade material, for it must be replaced periodically and does not provide a permanent and weatherproof structure.

Painted galvanized iron roofing sheets were compared similarly and the same beneficial effects of paints were noted. White paint applied to the top surface of galvanized iron caused a reduction of as much as 50° in its temperature, bringing it within a few degrees of the temperature of white-painted aluminum sheets. The addition of white paint to the galvanized iron sheet made it a "cooler" shade material than plain aluminum, establishing a lower radiant heat load beneath it.

The difference in radiant heat load and surface temperature among the different shades shown in the curves (fig. 13) will not always be of the same magnitudes. These differences may be less or greater, depending upon many environmental factors affecting the shades, such as wind velocity, air temperature, radiation from the sun and sky, and ground cover.

The combined desirable effects of white-painted top surface and black-painted undersurface were shown to help greatly in reducing the radiant heat load on an animal under a flat shade of aluminum or galvanized iron and should aid in increasing an animal's comfort.

White-painted Metal Buildings

During the summer of 1955 a study was made of the influence of white paint on the thermal environment within a metal building. The building was 60 × 32 feet, with the long dimension oriented north and south. The exterior of the south end and the south 20-foot section (sidewalls and roof) were painted with a flat white paint (fig. 14). The middle 20-foot section was painted with white paint supplied by the building manufacturer. The north section and north wall were left unpainted. Temperatures of the different building sections were measured with thermocouples attached to the inside surfaces. Surface temperatures for a 24-hour period are shown in figure 15. Maximum surface temperature reductions, due to the white paint, occurred at 1:00 P.M. when the air temperature outside the building was 100.0° F and inside, 102.5° F. These reductions were: west wall, 25.0° F; west roof, 42.6° F; and east roof, 41.0° F. There was little difference in the surface temperatures of the two ends even though the south end was in the sun all day. White paint effectively put the south end "in the shade." There was little difference in the effect of the two types of white paint, but the flat white did show a slight advantage over the building manufacturer's paint (fig. 15).

Since only one building with both painted and unpainted surfaces was used, it was not possible to directly compare

Fig. 14. Corrugated galvanized steel building, 60 × 32 feet. South end and south 20-foot section painted flat white, middle 20-foot section painted with building manufacturer's white paint, north section and north end unpainted.

Fig. 15. Inside surface temperatures over a 24-hour period of the walls and roof of the metal building shown in figure 14.

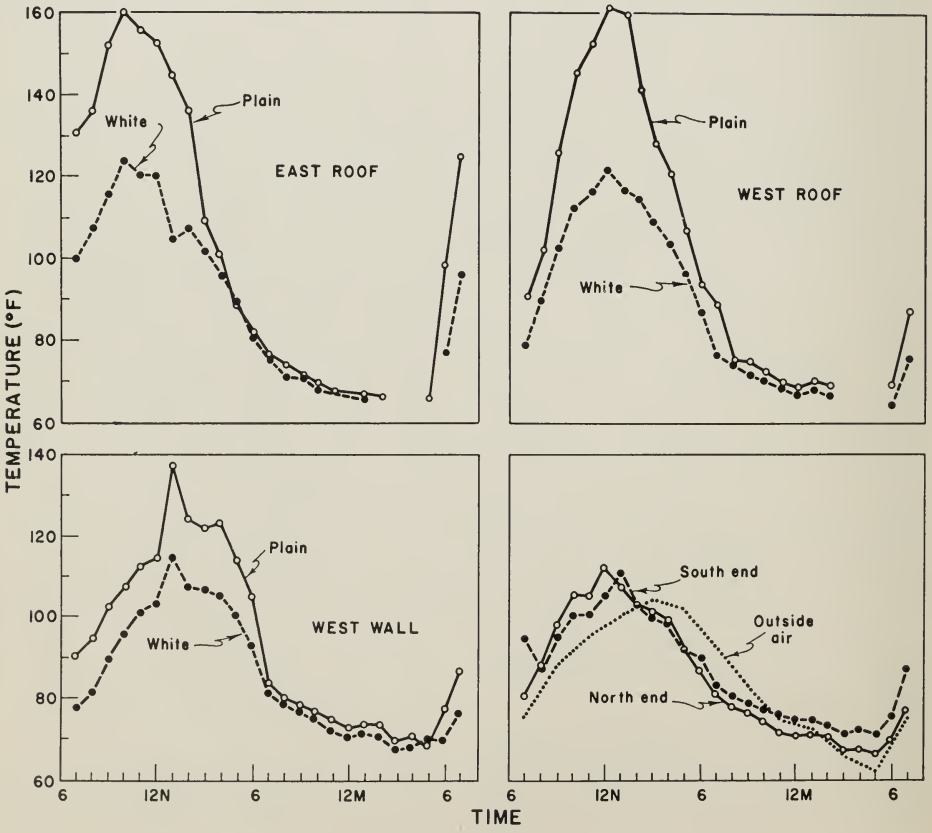


Table 5—Air temperatures in white-painted and unpainted corrugated galvanized steel building, 60' x 32', Imperial Valley Field Station, 1955

Date	Time	Inside Air Temperatures, °F.		
		White (measured)	Unpainted (theoretical)	Temperature difference
6/25	1:00 p.m.	102.5	130.5	28.0
6/25	2:00 p.m.	100.0	116.8	16.8
6/26	2:00 p.m.	102.5	119.8	17.3

air temperatures in painted and unpainted buildings. However, by theoretical considerations it was possible to show what the air temperature of a wholly unpainted building would have to be when heat was transferred to the inside air at the same rate as in the white-painted building, based on actual temperatures of the painted and unpainted sections at a particular time and with no ventilation. This was done and the resulting air temperatures are shown in table 5 for three different sets of surface temperature values.

Table 6—Radiosity (Btu/hr/ft²) of outside surfaces of metal barn and surrounding ground, 2:30 P.M., Imperial Valley Field Station, 1955

Surface	West side of barn (sun)	East side of barn (shade)
Unpainted	231	172
Manufacturer's white	311	179
Flat white	315	184
Ground	275	179

To show the ability of the white-painted surfaces to "lose" heat more readily than the unpainted surfaces, and thereby remain at a lower temperature, the radiosity* of these surfaces was measured with directional radiometer. One set of these readings is shown in table 6. The white surfaces in the shade gave off more heat, indicating a greater emission of energy than from the unpainted surfaces. In the sun the greater amount of energy from the white surfaces indicated both greater reflectivity and greater emissivity than the unpainted surfaces—very desirable characteristics in heat-load conditions for buildings.

* Radiosity—the total quantity of radiant energy leaving a surface per unit time per unit area. The radiosity may be due to energy initially emitted by a surface, to energy reflected from the surface, and to energy transmitted through the surface.

THE TESTS SHOWED | **that good shade will reduce the heat load as much as 50 per cent, and will increase gains**

Measurements in the tests indicated that properly designed shades will reduce the radiation heat load on an animal 50 per cent or more. Since sky temperature, solar radiation, air temperature, and other factors are never constant, no one shade can be best for all conditions.

Size of Shade. Most shades in this area vary from 16 to 20 feet in width and up to several hundred feet in length, depending upon the need. Wide shades cut down on the amount of cool sky radiating to the animal, although the larger shadow results in less radiation from the ground. The net result in cooling effect is about the same for both wide and narrow shades; however, wider shades reduce the drying effect from solar radiation, and unsanitary conditions may develop more easily.

Orientation. Most shades in the area are constructed with a north-south orientation. This usually allows enough sunshine under the shade to keep it dry and promote sanitation. East-west orientation allows more animals to be exposed to the cool north sky, and ground temperatures are a little lower because the ground is shaded for a greater part of the day. Even though east-west orientation decreases the radiant heat load on the animals, north-south orientation is preferred by cattlemen because it promotes better sanitary conditions.

Height. Raising the height of a shade gives the animal in the shadow a greater exposure to the cool sky and tends to increase the cooling effect. Cattle were found to prefer a shade 12 feet high rather than one 7 feet high. Although shadow size is not affected by height, the higher the shade the faster the shadow moves during the day. A high shade could lose its effectiveness by casting its shadow outside the corral for much of the day.

Higher shades receive sun under them for a longer time during the day than do lower shades, thus keeping the area drier. Moisture under a shade serves to lower the ground temperatures, but keeping just the right amount of moisture under a shade would be very difficult. It is probably more practical to plan on keeping this area on the dry side.

Shades betwen 10 and 12 feet high seem to be most practical. Men on horseback can ride under such shades without difficulty, cleaning equipment can be used, and the animals have a good opportunity to be exposed to the cool sky. Shades higher than 12 feet must make more allowances for strong winds. This makes them more expensive to construct and keep in repair.

Shade Material. Hay, galvanized iron sheets, aluminum sheets, and boards spaced 2-inches apart have all been tested as roofing material for shades. Hay is the coolest material tested to date. A 4- to 6-inch layer of hay has an insulating effect, and heat from the top does not penetrate through and radiate onto the cattle. Very little heat is reflected back to the animals from the underside of the shade. The underside of a hay roof stays very close to air temperature, thus reducing the radiant heat load. However, using hay as a shade roof does have its problems. Unless it is held together between two layers of wire, it tends to blow away. In a wet country hay can absorb a great amount of water during rainy periods and thus tends to break down the shade support unless it is well built. Even well-constructed hay shades must have the hay replaced periodically. Bamboo, palm

fronds, etc., give the same cooling effect as hay.

Galvanized steel sheets provide the exposed to the sun were found to have a temperature 20 to 30° higher than air temperature. The underside radiates this heat down onto the cattle. By painting the upper side white with a good chalking white paint much of this problem can be reduced; the galvanized steel sheets then come close to hay-covered shades in the resulting cooling effect on the animals. Galvanized steel and other metal sheets have the advantage of being more permanent than hay, and they shed rain during the wet season.

Aluminum sheets were found to be good shade material. They reflect much of the solar radiation. White paint was found to improve the reflecting qualities of aluminum as well as galvanized steel sheets.

Wood makes a good shade material, but leaving a crack between the boards allows the sun to fall directly on the cattle. This produces a hotter environment than a solid shade. Cracks appeared to reduce the fly population under a shade, but all the experiments to date show that a solid shade is definitely cooler. Figs. 16 and 17 show two types of shades that may be used in this area.

Although no tests have been conducted on the shade required per animal, a check of the shades used year after year indicate that 60 sq. ft. of shade per animal is practical. Many feeders provide between 40 and 50 sq. ft. of shade, but animals should not be crowded during the summer months.

Fig. 16. This wooden roofed shade is practical in areas where small whirlwinds tend to destroy hay covered shades. Cracks between boards should be kept to a minimum.

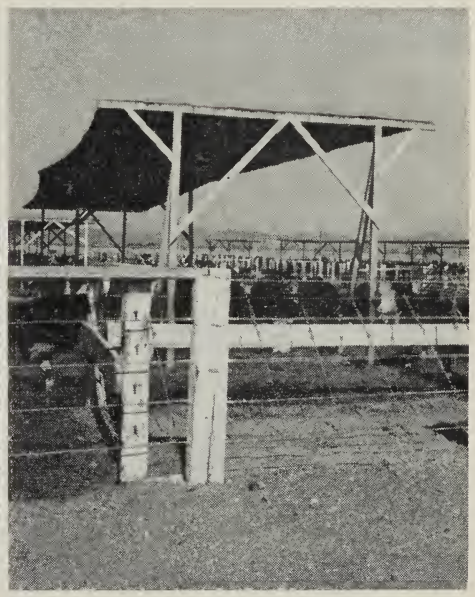


Fig. 17. This 11-foot hay shade is supported by cables and the hay is sandwiched between two layers of light fence wire. Note the cable fences.

WATER AS A COOLING AGENT

Water is an ideal cooling agent; it usually is cheap and abundant, and it can be economically transported to the animals; it is noncorrosive and nontoxic; it has the highest heat capacity of any of the common liquids (1 Btu per pound/° F) and also the highest latent heat of evaporation (1050 Btu per pound at 70°). This discussion covers tests over the period 1947-1955 that used water as a cooling agent in four different ways: (a) spraying the animals, (b) cooling the air, (see page 52), (c) cooling the shade surfaces, (see page 22), and (d) cooling the drinking water.

Spraying the Animals

Spraying dairy cattle with water has been investigated by Seath and Miller (1948). The effect of wallows and rain on water buffalo, Zebu cattle, and sheep was studied in India by Minett (1947). European- and Indian-evolved cattle lack sweat glands as they are found in man. However, they do lose moisture and are cooled by the evaporation of water from the skin, more so than originally thought. Kibler and Brody (1952) have shown that at temperatures above 75° F Jersey and Holstein dairy cattle will lose about two-thirds of their insensible (latent) heat of metabolism through the skin and only one-third by way of the lungs. This evaporative cooling of the body is not enough to prevent discomfort when environmental temperatures are above the critical range (75° to 85° F). At air temperatures of 105° F all heat produced was dissipated by evaporative cooling.

Cattle sprayed with water will be cooled by the evaporation of the water from their skin and by conduction when the water temperature is lower than the skin temperature. This was first shown in tests made in 1946, when some preliminary studies were conducted with dairy cattle. At an air temperature of about 109° F and a relative humidity of 18 per cent, wetting cows with a garden hose reduced body temperature about 1.5° and slowed respiration rates by about 20 breaths per minute.

The spray tests reported herein were conducted each summer, from 1947 to 1952 inclusive, except for 1948. The results are summarized in table 7, together with the number and breed of animals and their initial weights. Water temperature at the nozzles varied from 85° to 95° F in all the tests. Following are brief descriptions and results of the studies, by year:

In 1947 three Hereford heifers were housed under a 16×24-foot aluminum shade equiped with three shower heads giving a fine spray. The spray heads were 8 feet above the ground. Water pressure at the heads was 30 pounds per sq. in. A concrete slab under the shade carried the waste water to a drain. The animals made little use of the sprays, got only the ends of the hairs wet (not their skins), and did not seem to be getting any measurable benefits. One spray head, with the hole enlarged to $\frac{1}{8}$ inch to wet the animals to the skin, was then lowered to 6 feet above the ground, cutting down the drift. When the animals were also wetted down with a hose several times, to show them the benefits of standing under the shower, they began to make greater use of the spray. By the end of the summer one animal was standing under the shower about three hours per day. Occasionally, even though the shadow movement left the showering animal exposed to the sun, it nevertheless stood under the shower even when the air temperature was 109° F (fig. 18).

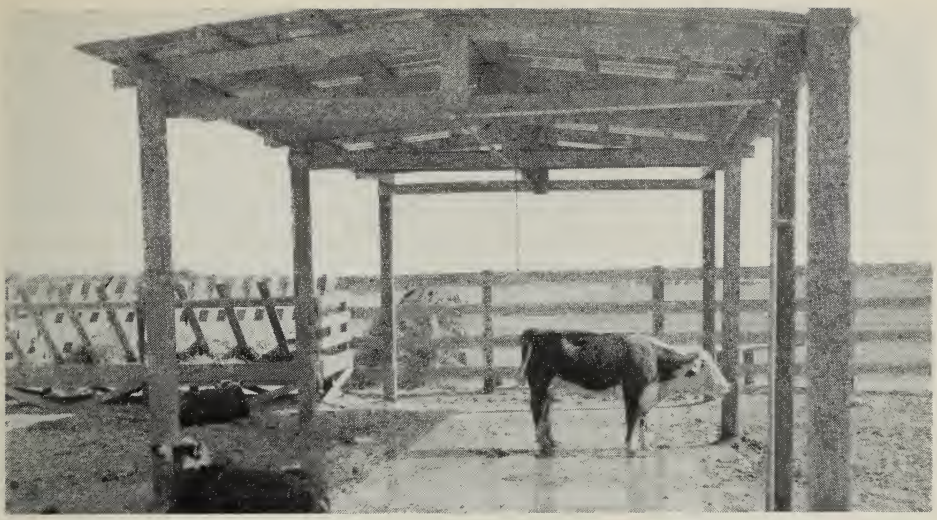


Fig. 18. Yearling Hereford standing in sun, with air temperature at 109°F, in order to take advantage of spray.

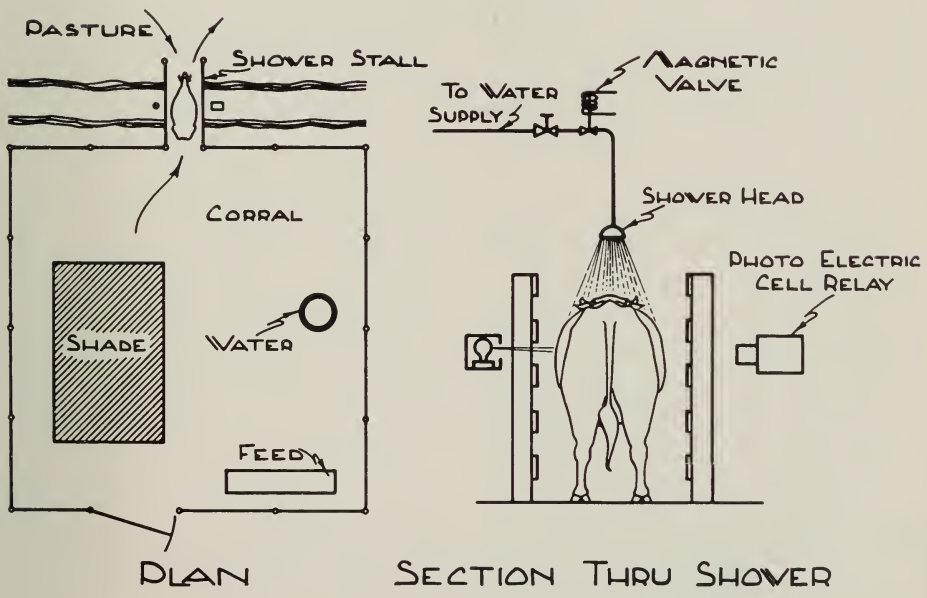


Fig. 19. Single shower head controlled by photoelectric cell relay. Plan shows relation between shower stall, shade, and pasture. Section indicates position of relay with respect to shower stall and animal.

Wetted animals usually had body temperatures 2° or 3° lower than those of dry animals, and lower respiration rates by 20 or more breaths per minute. These animals never used the sprays at night; even when the night temperature did not go below 80° F, they preferred standing in the open, exposed to the cooler sky. The continuous operation of the showers used excessive amounts of water and created unsanitary conditions under the shade, even though the floor was concrete. Weight records and feed records were too meager in 1947 to indicate any advantage between the spray and check pens.

In 1949 (there were no spray tests in 1948) an inexpensive photo-electric cell relay ($30) and an electric solenoid water valve were used to control the water flow to a single coarse shower head (fig. 19) so that the shower operated only when an animal entered the stall. The shower was installed over an irrigation ditch so that waste water went directly into the ditch. The shower, with standing room for only one animal, was situated between shade and irrigated alfalfa pasture. It was anticipated that the cattle would wet themselves at frequent intervals when passing to and from the pasture, thus increasing grazing time. The 8 check animals were at the wood corral and had access to pasture. Feed records were not kept on these animals.

Several of the 8 test cattle (table 7) used the shower very little, partly because they never learned its comfort and partly because "boss" cows would not let them into the stall. In spite of this, the average daily gain of the test pen during the 66-day feeding period (July 12–September 16) was 0.37 pound per animal greater than the gain of the unsprayed, check cattle. This difference in gain may have been influenced by the corrals since the shower group was in a wire pen and the check animals were at the wood corral.

In 1950 the shower stall was widened to 6 feet, three shower heads were installed, and the number of test animals was reduced to four so that all would have equal opportunity to shower. All animals used the spray a great deal of the time during the day. They received all the alfalfa and barley hay they wanted but made little use of the pasture. They seemed to enjoy the water and were definitely more comfortable than the unshowered check animals. The check steers were also in a wire pen, had access to pasture, and were fed the same as the test group. The average daily gain during the 80-day feeding trial (June 21–September 9) was 0.22 pound greater than the gain of the check animals (table 7). Because of a shortage of irrigation water the showers were not operated during three or four days of each month. A view of the shower stall in operation is shown in figure 20.

Fig. 20. Shower stall, located over irrigation ditch, in use in tests of 1950. Water flow is controlled by photoelectric cell relay.

In 1951 a test using very fine mist sprays was conducted in a feeding trial with 5 Shorthorns (2 steers, 3 heifers). The check pen had 4 Shorthorns (2 steers, 2 heifers), and both lots were fed at the wooden corrals from July 3 to September 27. These spray nozzles, known as "foggers," have been used with some success in California to prevent the death of

Table 7—Summary of tests using sprinklers and misty sprays for cooling cattle*

	1949†		1950		1951		1952	
	Shower	No shower	Shower	No shower	Misty spray	No spray	65° F. water and misty spray	65° F. water
Breed of animals	Herefords	Herefords	‡	‡	Shorthorn	Shorthorn	Hereford	Hereford
Number of animals	8	8	4	4	5	4	10	10
Length of feeding trial	66	66	80	80	86	86	71	71
Av. initial weight	644	628	851	831	827	846	765	761
Av. final weight	747	708	967	930	968	981	831	835
Av. daily gain	1.57	1.20	1.45	1.23	1.64	1.58	0.94	1.04
Av. daily feed	....	....	§	§	....	....	....	....
Barley	....	....	....	....	4.74	4.69	....	....
M.D.B.P.	....	....	....	....	3.16	3.21	....	....
Alfalfa hay	....	....	4.14	4.11	12.12	11.37	20.80	20.35
Barley hay	....	....	4.14	4.11	1.93	2.36	....	....
Total	....	....	8.28	8.22	21.95	21.63	20.80	20.35
Feed per 100 lb. gain								
Barley	....	....	....	....	289	297	....	....
M.D.B.P.	....	....	....	....	192	204	....	....
Alfalfa hay	....	....	286	334	737	720	2221	1958
Barley hay	....	....	286	334	117	150	....	....
Total	....	....	572	668	1335	1371	2221	1958

* The year 1947 not shown as weighing facilities were poor.
† Both lots on pasture, check animals in wood corral, test animals in wire corral.
‡ One pure-bred Hereford and 3 Hereford-Shorthorn crosses.
§ Received hay and pasture in 1950.

laying hens confined in cages during hot weather (Wilson and Hillerman, 1952). Although mists did not prove successful in 1947, it was thought that the extremely fine mist produced by these nozzles might prove more efficient in cooling, simplify the spraying equipment, cut down the amount of water needed, and increase sanitation under the shade. Monarch No. H-61 nozzles were used, delivering 1 gallon of water per hour under a pressure of 20 pounds per sq. in. (manufacturer's rating).

Six nozzles, 6 feet above the ground and out of reach of the animals' backs, were arranged under the same 16×24-foot shade used in 1948, in two rows of three nozzles each. Nozzles were 8 feet apart in the rows, and the rows 7 feet apart. The concrete slab was enlarged by 3 feet all around to improve the sanitary conditions.

The average daily gain was good for both test and check animals (table 7), but the "fogged" animals gained only 0.06 pound per day per animal more than the check animals, which was not significant. However, the feed consumption per 100 pounds of gain was slightly less with the fogged group. The animals under the foggers appeared uncomfortable and particularly avoided getting their heads in the moisture. Their hair was seldom wet enough to be plastered down to their skins. In fact, the beads of moisture sometimes appeared to cause the long hair to stand out from the skin, thus actually increasing insulation against heat transfer from skin to air. These animals received some grain in their ration, which may have masked benefits from the fogging.

In 1952, therefore, fogging was tried again, with hay as the only ration. The number of nozzles was increased to 18 and the concrete slab again increased, this time to 30×40 feet. The arrangement of nozzles, shade, and slab is shown in figure 21, along with air temperature and relative humidity observations made at 1:15 P.M. on September 8, 1952, with the air temperature at 109° F and humidity 17 per cent. Some of the nozzles were always in shadow.

Ten Herefords were used for the feeding trial, with 10 similar animals in an unfogged corral as checks. The test was run from July 2–September 11. All 20 animals had their drinking water cooled to 65° F. (See discussion below on cooling drinking water). Time of spray operation was as before, from about 8 A.M. until 4 to 5 P.M.

The sprayed animals with cool drinking water gained 0.10 pound per animal per day less than unsprayed cattle with cool drinking water (table 7). Later tests have indicated that 10 head may have crowded the animals a little too much and not allowed as many square feet of shade per animal as is necessary. (See page 33.)

During the same summer a short trial (not a feeding experiment) was made with a commercial mechanical "fogger"—a whirling wire brush, driven by a ¾-HP motor, that dispersed atomized water from its periphery by centrifugal force (fig. 22). Droplet size could be adjusted by varying the rate of water flow. When droplet size appeared about the same as that produced by the fogger nozzles, the air temperature was lowered from 110° to 95° F as far as 10 feet from the wheel. The animals were not wetted appreciably and avoided getting their heads in the moist clouds, but they seemed to like the lowering of the air temperature and the air movement induced by the rapidly whirling brush.

The cooling effect of sprays on animals is due to several different mechanisms. Wetting the animal to the skin produces cooling by conduction when water temperature is lower than skin temperature; the amount of the difference in temperature and the rate of water flow determine the amount of cooling. Further cooling will result from the evaporation of water that does not run

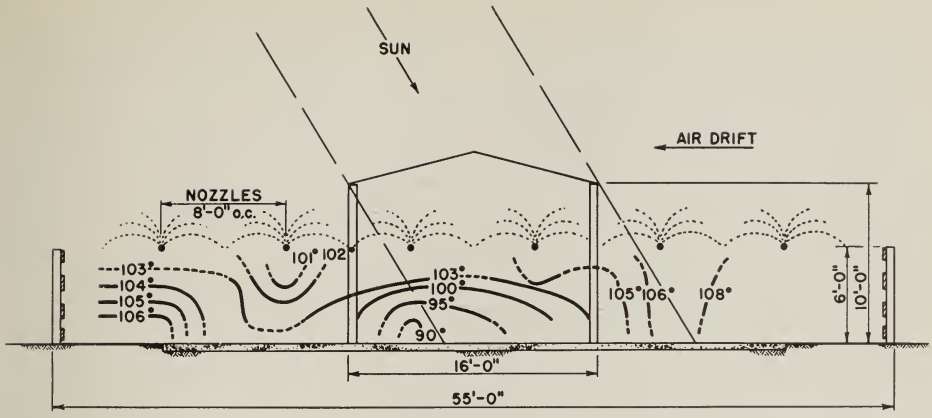
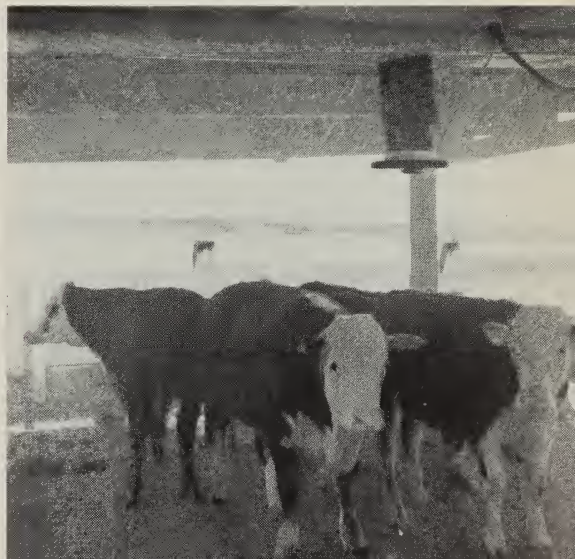


Fig. 21. Arrangement of fogger nozzles under 16 × 24-ft. shade in 1952 tests. Air temperature isotherms are for September 8, 1952, at 1:10 p.m., when outside temperature was 109°F.

off the animal. (This will be the greatest cooling if the rate of water flow is curtailed by a limited water supply). Part of the heat for evaporation will come directly from the animal by conduction, and part from sensible heat of the air. Cooling of air may or may not be of benefit, depending upon the opportunity the cooled air has of circulating back around the animal. The rate of heat loss from the animal surface (by convection, radiation, and evaporation) will vary directly with changes in the surface temperature of the animal due to wetting. As shown in figure 23, the animal-surface temperature may be expected to decrease through the evaporation of water. This can only decrease the rate of heat loss from the animal's surface by convection to the air and by radiation to the surround. At higher environmental temperatures the direction of heat flow by these modes may actually be reversed, with heat flowing from the environment into the animal surface. The heat balance is further complicated by the animal's physiological reaction to a lowered skin temperature. Internal body heat flows toward the surface at an increased rate, by conduction through the body tissues and liquids. A lowered skin temperature will also change that part of heat-transfer rate established by blood flow. The literature is not clear on peripheral circulation of blood and vasomotor activity of cattle when subjected to high temperatures. Some work has shown that in contrast to man, the pulse rate of non-sweating animals is higher in a comfortable environment than in a hot one (Worstel and Brody, 1953). Recent

Fig. 22. Whirling-brush fogger device installed under shade in 1952 test. Note that animals all face away from fogger.



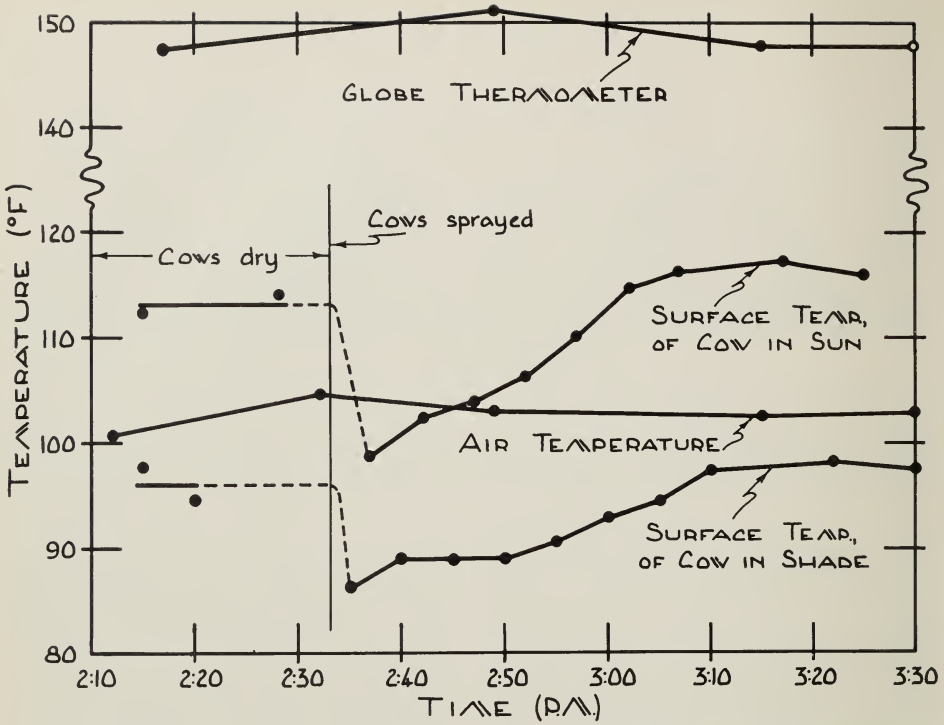


Fig. 23. Surface temperature of Brown Swiss cow in sun and in shade, before and after wetting, with air temperature and globe-thermometer temperature in sun.

work by Beakley and Findlay (1955) with 4-month-old Ayrshire bull calves showed an increase in heart rate with increasing environmental temperatures above 68° F and with increasing humidity above a temperature of 86° F. However, even less information is available on the effect of artificial wetting upon blood flow.

A number of cattle under one set of sprays will increase by evaporation the humidity already present from water droplets in the air. This may cause discomfort to adjacent animals by decreasing evaporation from their wetted surfaces. If the dry-bulb temperature of the air is above 85° F, this increased humidity will decrease heat loss from adjacent unwetted animals also, as recently shown with dairy cows by Thompson, Worstell, and Brody (1953).

This increase in humidity, in the area where cattle are under sprays with high air temperatures, may be the weak link in trying to cool cattle by this method. Wetting the animals with heavy sprinkling has seemed more effective than the foggers, but this is expensive and creates the problem of keeping the yards sanitary where large numbers of cattle are involved. High humidity not only reduces the cooling effect from evaporation, but high humidity with high air temperature (75°–100° F) causes a decided increase in rectal temperature and respiration rates of dairy cattle (Kibler and Brody, 1950). These facts may explain why the sprinklers and misty sprays were not too effective, since the animals were under them during most of the day.

Cooled Drinking Water

The methods of cooling beef cattle discussed so far have all depended directly or indirectly upon evaporative cooling

effects. It was thought that cooling the drinking water might indirectly increase evaporative cooling by increasing water consumption, thus providing more water for loss through skin and lungs. At the same time there would be some direct cooling by transfer of body heat to the cool water in establishing a heat balance due to conduction in the body fluids. In the Imperial Valley livestock drinking water, supplied mostly from irrigation ditches, may reach temperatures as high as 90° F in the ditch and 100° F in the drinking troughs. Experiments have been carried on with cooled drinking water for five years, 1950 through 1955 (table 8).

In 1950 two groups of Herefords, including 3 steers and 1 heifer each, averaging 840 pounds in weight, were used to measure the effect of cool drinking water. Both groups were fed a ration containing 75 per cent alfalfa hay and 25 per cent barley hay. The two groups were placed in separate wooden corral pens, each pen provided with a circular concrete water tank 30 inches high and 36 inches in diameter. The tank in the cool water pen was insulated with commercial insulation and the top covered with 2-inch planks, except for a small opening for the cattle to drink through. The water in this tank was maintained at 65° ± 2° by a ¾ horsepower mechanical refrigeration unit with direct expansion coils immersed in the water. A small pump at the bottom of this 110-gallon tank provided agitation and kept the cold water from settling to the bottom.

The mean air temperature and humidity for the test period (June 14–September 5) are shown in table 1. The lowest reading recorded was 54° F and the highest 118° F. Only 29 days of the period had minimum readings below 70° F. Average water temperature for the warm water pen was 88.2° F.

Table 8 gives the rates of gain, food consumption, and feed per 100 pounds of gain for each group of animals. The four Herefords receiving cold water made an average daily gain of 1.46 pounds per day, those in the warm water pen gained 1.07 pounds. This difference in daily gain of 0.39 pound is significant at the 5 per cent level.

In 1951 a small evaporative cooling tower (fig. 24) was used to cool the water in an attempt to reduce costs in comparison with the mechanical refrigeration system. According to Perry (1945), the performance of such towers depends upon tower design, wind velocity, water-circulation rate, and heat load. A well-designed tower will give a final water temperature within 5° of the wet-bulb temperature if wind velocity is as little as 1 mph. The tower constructed had eight 30 × 40-inch trays, spaced 8 inches apart, of ¼-inch mesh hardware cloth. Water circulation was at the rate of 6 gal/min. Water consumption of four animals was estimated as 60 gallons per day. The heat load to cool this amount

Fig. 24. Small evaporative cooling tower used for lowering temperature of drinking water in 1951.

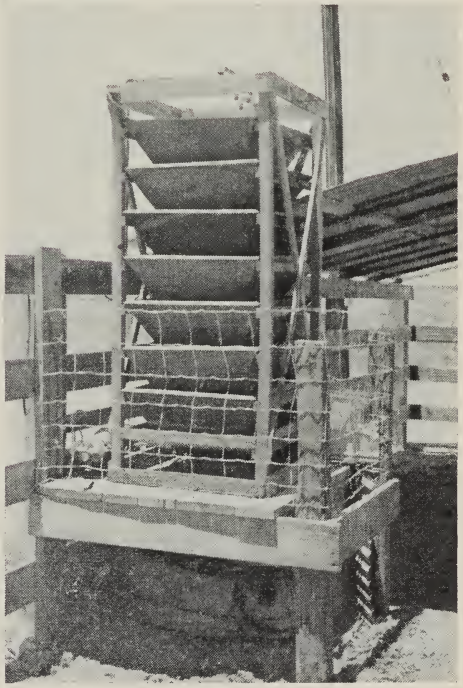


Table 8—Summary of tests conducted with cool drinking water for beef cattle from 1950 to 1955

	1950		1951		1952		1953	
	65° F. water Hereford	Warm water Hereford	75° F.* water Shorthorn	Warm water Shorthorn	65° F. water Hereford	Warm water Hereford	65° F. water Hereford	Warm water Hereford
	Hay	Hay	Hay and grain	Hay and grain	Hay	Hay	Hay and grain	Hay and grain
Number of animals	4	4	5	4	10	10	6	7
Length of feeding trial	83	83	86	86	71	71	84	84
Av. initial weight	849	833	839	846	761	768	881	869
Av. final weight	970	922	973	981	835	823	1049	1000
Av. daily gain	1.46	1.07	1. 56	1.58	1.04	0.78	2.01	1.57
Av. daily feed								
Barley	....	....	4.7	4.7	....	....	5.8	4.3
M.D.B.P.	....	....	3.2	3.2	....	....	2.9	2.2
Alfalfa hay	17.7	16.9	11.4	11.4	20.4	19.4	10.8	11.5
Barley or oat hay	5.9	5.5	1.9	2.4	....	....	2.0	2.0
Total	23.6	22.4	21.2	21.7	20.4	19.4	21.5	20.0
Feed per 100 pound gain								
Barley	....	....	305	297	....	....	291	277
M.D.B.P.	....	....	203	204	....	....	146	138
Alfalfa hay	1212	1577	733	720	1958	2481	539	737
Barley or oat hay	406	515	125	150	....	....	97	127
Total	1618	2092	1366	1371	1958	2481	1073	1279

	1953		1954		1954				
	65° F. water Hereford	Warm water Hereford	65° F. water Hereford	Warm water Hereford	Salt 65° F. water Hereford	Salt Warm water Hereford	60° F. water Hereford	70° F. water Hereford	Warm water Hereford
	Hay	Hay	Pellets†	Pellets†	Salt pellets†	Salt pellets†	Hay & grain	Hay & grain	Hay & grain
Number of animals	7	7	7	7	7	7	7	7	7
Length of feeding trial	84	84	84	84	84	84	70	70	70
Av. initial weight	867	868	815	815	811	817	668	671	669
Av. final weight	993	967	957	942	937	940	786	796	759
Av. daily gain	1.51	1.18	1.70	1.51	1.50	1.47	1.69	1.79	1.29
Av. daily feed									
Barley	....	....	16.4	16.4	17.8	17.1	4.7	4.7	4.2
M.D.B.P.	....	....	....	....	....	....	2.2	2.1	1.9
Alfalfa hay	18.9	17.9	....	....	....	....	10.2	9.7	9.1
Barley or oat hay	2.0	2.0	1.1	1.1	1.1	1.1	1.9	2.9	1.9
Total	20.9	19.9	17.5	17.5	18.9	18.2	19.0	19.4	17.1
Feed per 100 pound gain									
Barley	....	....	966	1085	1186	1159	280	262	327
M.D.B.P.	....	....	....	....	....	....	128	120	149
Alfalfa hay	1259	1524	....	....	....	....	603	543	706
Barley or oat hay	136	170	64	72	72	74	114	164	148
Total	1395	1694	1030	1157	1258	1233	1125	1089	1330

* A small evaporative cooling tower was used to lower the water temperature.
† Pellets—Ground barley 35%, dried beet pulp 15%, alfalfa hay 35% and oat hay 15%. Salt content of pellets, 10%.
‡ One animal died from causes not associated with the experiment.

of water from 95° to 70° F was calculated to be 12,500 Btu. This was doubled, to allow for estimated reheating through the warming of the tank by radiation and convection. The resulting heat load of 25,000 Btu would have to be handled during the period when most of the water is drunk—about 9 hours during the daytime. The rule of thumb stating that 1 sq. ft. of screen area is needed for each 10 Btu to be dissipated per minute was then applied.

The average water temperature maintained by the tower for the 86-day summer feeding period (July 3 to September 27) was 75.4° F, an average cooling of around 9° to about 3° above the average daily wet-bulb temperature. The circulation pump was operated from 8 A.M. to 4 or 5 P.M. However, there were 35 days when the water averaged 78.5° F, and 21 days when it averaged 70.8° F. Of these 21 days, 10 came after September 3. During humid days evaporative cooling was very poor and water temperatures ran around 80° F, but on dry days temperatures dropped as low as 66° F. Weather data in table 1 shows that 1951 was the coolest year in respect to temperature, but it had the highest relative humidity of any of the 10 years that these tests were run.

Water in the warm water tank had an average temperature of 84.2° F, so the average difference between these two water temperatures was only 8.8°.

Shorthorn steers were used in 1951, since they were available and are considered less heat tolerant than Herefords. The steers were in very good condition and averaged 842 pounds at the beginning of the experiment. Five steers were in the cool water pen and four in the warm water pen, and they occupied the same pens in the wooden corral as the cool and warm water steers in 1950. Instead of feeding alfalfa hay, they were given a ration of hay and grain. Both groups of steers gained the same, 1.56 pounds per head per day for the 75° F water, and 1.58 pounds for the warm water. Feed consumption and economy of gain were almost identical (table 8).

High humidity during this summer was a definite factor in the result of this test. Humidity prevented the cool water from being cooler, and it has been shown that animals in surroundings of high temperature and high humidity are under more thermal stress than animals exposed to high temperature and low humidity. The grain diet did give the steers a lower increment of heat, and they all made fairly good gains.

In 1952 experiments repeated the 1950 test with the water cooled to 65° F by mechanical refrigeration, and the animals were fed hay. This refrigeration unit had a 3-ton capacity and is shown in figure 25. Ten Hereford steers averaging 764 pounds were put on a 71-day feeding trial (July 2 to September 11), with 10 similar Herefords receiving uncooled water as a check. Uncooled drinking water averaged 89.6° F and ranged from 70° to 102° F. Table 8 shows the results of this test. The difference in daily gain between the cold and warm water lots was 0.26 pound in favor of cold water and was not significant. Ten animals per pen may have been too many, especially in the cold water lot which had only 41 square feet of shade per animal. These shades might have been adequate if some animals had not had to stand near the hot fence. Individual data also indicate that the "boss" animals may have selected the cooler spots for themselves.

(See page 33 for further discussion of the square feet of shade needed by animals).

In the 1953 tests clarification was sought concerning the relationship between hay and grain rations and between warm and cold water. For these tests four pens each, with seven Hereford steers averaging 871 pounds, received the following treatments during an 84-day test period (June 30 to September 22): (a) cold water and hay, (b) cold

water and hay plus grain, (c) uncooled water and hay plus grain, and (d) uncooled water and hay. The average daily gains for this test were: cold water-hay, 1.51 pounds; cold water-hay plus grain, 2.01 pounds; warm water-hay plus grain, 1.57 pounds; and warm water-hay, 1.18 pounds. As for the hay- and grain-fed animals, the average daily gain of those on cooled water was 0.44 pound greater than that of animals on uncooled water. With hay-fed animals, cooled water produced 0.33 pound greater daily gain than did the uncooled water (table 8). Analysis of this study shows no significant interaction between feed and water effects; furthermore, each of the main effects (feed and water) is significant at the 1 per cent level. (See page 76 for further discussion on feed effects in hot climates).

In the 1954 tests, since 65° F drinking water seems to be a significant factor in the heat-regulatory mechanism of cattle, it was decided to increase the salt in the ration to see if they would drink more cool water and thus gain even faster. In recent years a salt-and-concentrate mixture has been used extensively in the range country to control the concentrate intake of animals self-fed on pasture. This high-salt diet has nearly doubled the animals' water requirements (Riggs, Colby, and Sells, 1953). In the four previous experiments it is interesting to note that animals with cool drinking water consumed slightly less water than those with the warm water. (table 9).

In order to get the animals to consume excessive amounts of salt, two pelleted diets were prepared. Both contained the following: 35 per cent alfalfa hay, 15 per cent oat hay, 35 per cent barley, and 15 per cent molasses-dried beet pulp. Ten per cent salt was added to one lot of pellets and none to the other lot. All lots had block salt in their pens.

Seven Hereford steers, averaging 814 pounds, were placed in each of four wooden pens and given the following treatments: (a) 65° F water plus pellets, (b) 65° F water plus pellets with 10 per cent salt. (c) warm water plus pellets,

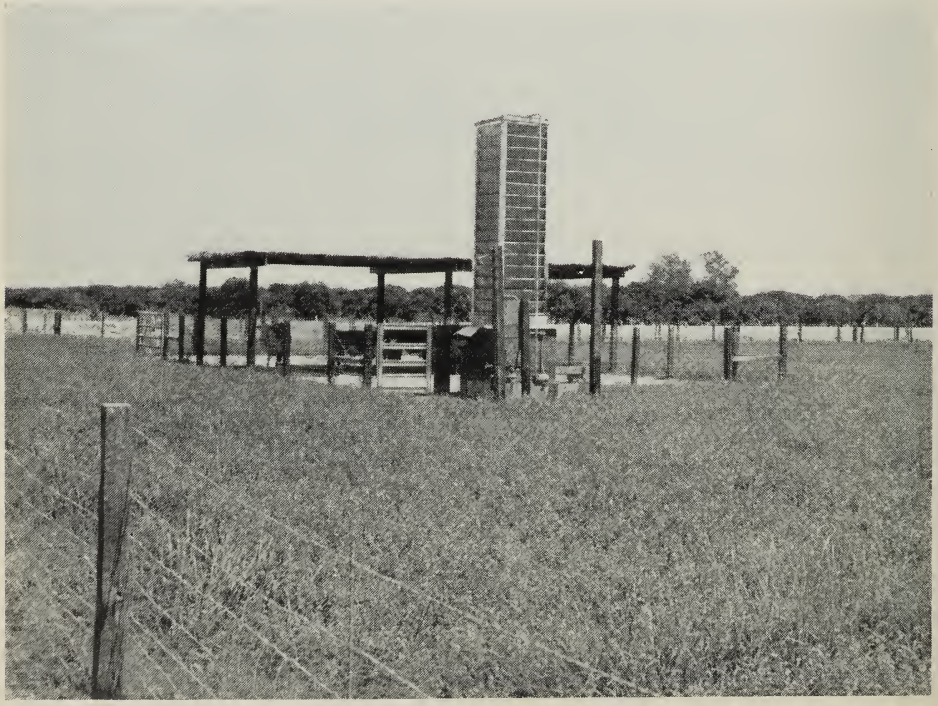
Table 9—Comparison of consumption of cooled and uncooled water, and cooling effects calculated

		Av. daily water consumption per animal		Av. temp. of uncooled water (°F)	Daily difference in cooling effect per animal* (Btu)
		Water cooled to 65°	Uncooled water		
		(gal.)	(gal.)		
1950		15.4	16.6	88.2	2831
1952		13.4	15.0	89.6	2348
1953	Hay ration	13.6	†	89.2	....
	Grain ration	11.3	13.0	89.2	2084
1954	No salt	12.6	14.1	86.3‡	2030
	Salt	20.3	19.5	86.3‡	3718
1955	60° water	10.9§	12.4	87.7	1583
	70° water	11.0§	12.4	87.7	1446

* Based on raising daily consumption of water of the two different temperatures up to estimated body temperature of 103°.
† Water consumption not measured.
‡ Unshaded first month of test then shaded.
§ Water temperature as shown under year.

Fig. 25. Mechanical refrigeration equipment and controls used for cooling drinking water from 1952 to 1955. The tower is for cooling condenser water.

Fig. 26. Large evaporative cooling tower mounted above 4 × 4 × 4-foot metal water tank.



and (d) warm water plus pellets with 10 per cent salt. During the first 28 days of the test all lots developed an appetite for the wooden mangers and corral fences, but with the addition of 1 pound of oat hay per day this tendency was eliminated.

Daily gains, food consumption, and economy of gains are shown in table 8. Although the daily food consumption was higher in the salt pens than in the others, each animal ate 1.7 pounds of salt per animal per day. This means that their daily food intake was less. Water consumption by the salt-fed animals did not double, but it increased about 40 per cent in the warm-water pen and 60 per cent in the cool water pens (table 9). Average daily gain for animals with salt pellets and cooled water was 0.03 pound greater than that of animals on warm water. With the steers receiving block salt, 65° F drinking water produced 0.19 pound greater daily gains than the uncooled water.

The greater water consumption, due to the salt in the diet, did not seem to give the steers any added comfort, nor did the salt show any detrimental effect on average daily gain, efficiency of feed utilization, or dressing percentages. The salt lots did show a decrease in carcass grade when compared to the low-salt groups (Meyer, et al., 1955).

Since mechanical refrigeration of drinking water is expensive, two cheaper methods were tested during the summer of 1954. For the first two months a larger evaporative cooling tower ($4 \times 4 \times 14$ feet) was used to cool the water. The last month water was cooled by a 36-inch fan placed horizontally 6 feet above a $4 \times 4 \times 4$-foot insulated metal water tank. This cooling tower was much larger than the one used in 1951 and was mounted above the water tank as shown in figure 26. A ¾ HP pump circulated water over the tower between 2 A.M. and 5 A.M. The tank held enough water to supply seven 816-pound Hereford steers with water for three days. Two cattle drinking cups were fitted to the outside, close to the bottom of the tank so that the coolest water in the tank was available to the animals. Each day the tank was refilled during the time the pump was operating. These operations were controlled by a time clock and a solenoid valve. Water was circulated during the early morning hours because the air temperature was at its lowest; although relative humidity was higher, the dew point was at its lowest for the 24-hour period, which would bring the water temperature of the tank to the lowest possible level.

Louvers in the cooling tower were removed during the month the fan was operated. Another set of louvers was placed at the surface of the water in the tank to protect the surface from daytime radiation and to gain the benefit of nocturnal cooling by radiation of the water surface to the cold sky. Fan operation was from 7 P.M. to 7 A.M. and was regulated by the time clock. Water was added when the fan started to operate.

The average water temperature for the cooling tower during the first two months of the test was 70.2° F, while during the last month the fan was used the water temperature averaged 71.3° F. The cooling tower lowered the water temperature in three hours, while with the fan it took 12 hours for the water to reach about the same temperature. On days with low humidity, water temperature was as low as 50° F and on humid days the water averaged around 79° F. Water in the tank had a gradual 4° to 5° increase in temperature during the day.

The pen with the cooling tower was wire, and the animals were compared to another group of steers in a wire pen with drinking water at 81.4° F. Both groups of Herefords were in a cooler environment and the 10° difference in water temperature did not produce a significant difference in gain. Cattle with the water from the cooling tower made an average daily gain of 2.03 pounds and

the other lot gained 1.94 pounds. The feed, treatment, and efficiency of gain of these two groups are shown in table 10. The effect of wire pens is discussed more fully in the section entitled "Natural Air Movement."

In 1955 a further test with cool water was conducted to check the effect of 60°, 70° F, and warm drinking water for cattle. The three pens each contained seven Hereford steers, which were fed grain and alfalfa hay and had adequate shade. These animals were tested in the heavy wooden corrals. Water temperature for the warm pen averaged 87.7° F.

This experiment ran from July 6 to September 14, and the steers in the check pen gained 1.29 pounds per head per day, while those receiving 60° F drinking water gained 1.69 pounds per head per day, and the animals with the water at 70° F gained 1.79 pounds per head per day. A 10° difference in water temperature did not make a significant difference in daily gain, but both the cool water pens gained significantly faster than the check lot (table 8).

Results from the six years' tests were uniformly in favor of drinking water cooled to a constant temperature of 60°, 65°, or 70° F. For the period, the average superiority in daily gain per cooled-water animal was 0.36 pound—excluding the 1951 test, when the evaporative cooling tower cooled the water only to an average of 75.4° F, and the 1954 test when salt was used in the ration. As shown by the average rate of water consumption in table 9, this superior weight increase cannot be due to increased water consumption, since actually the animals always drank less of the cooled water. Compared to the total metabolism of the animals, the cooling effect of cooled water was very small, never totaling more than 2,831 Btu per animal per day (for animals without salt)—about 4 per cent of the average daily heat production (table 9). This figure is also low when compared with the estimated lightening of heat load by shade, 1,344 Btu per hour at 100° F as reported above.

A report by Bligh (1955) shows that the temperature of the blood leaving the left side of the heart is only slightly lower than the rectal temperature of the animal. This would indicate that upward changes in rectal temperature in re-

Table 10—Average weights, daily gains, and food consumption of seven Hereford steers in a wooden corral and seven Herefords in a wire corral

(June 24–September 16, 1954)

Item	Wooden corral	Wire corral	Wire corral cool water
	Lb.	Lb.	Lb.
Av. initial weight	815	814	816
Av. final weight	942	977	986
Av. daily gain	1.51	1.94	2.03
Av. daily feed (pellets)*	16.4	16.8	17.4
Oat hay	1.1	1.1	1.1
Feed per 100 lb. gain (pellets)	1085	867	860
Oat hay	72	56	53

* Pellets = 35% barley, 15% molasses dried beet pulp, 35% alfalfa hay, and 15% oat hay.

sponse to external heat stress indicate changes of a similar magnitude in "deep body temperature."

Since body temperature is a good index of the external heat stress on an animal, a series of body temperatures was taken on four Hereford steer calves to study the effect of cold (60° F) and hot (87° F) drinking water on the body temperatures. Getting the calves to drink about the same amount of water and to behave alike was a problem. On September 1, 1955, with air temperature at 108° F at 2:00 P.M., a very good test was conducted with all parties cooperating. At 7:30 A.M. the four calves were fed alfalfa hay in a corral without water but with shade. Then at 12:15 P.M. all four calves were tied up in the shade and their body temperatures recorded; they were then allowed to drink, and a series of body temperatures was taken as indicated in table 11.

This test and others run during the summer show that there is some reduction in body temperature when either hot or cold water is consumed. Cold water has more effect on body temperature than warm water and for a longer period of time. In this case the average reduction of body temperature for the warm water was 0.35°, while the cold water reduced temperatures 1.55°.

Although the cool water has a decided cooling effect on the animals, there are probably other physiological reasons besides heat loss which account for the increased gains due to the cool drinking water. These experiments demonstrate the significance of drinking water as a part of the heat-regulatory mechanism of cattle. Perhaps the cool water cools the food mass in the rumen so that the heat of digestion is slowed down, or it may cool the thermoregulatory section of the brain, with the cooled blood bringing the whole body closer to thermal neutrality for several hours.

Table 11—Body temperature differences of Hereford calves drinking 60° and 87° water with air temperature at 108° F.

(September 1, 1955)

	Calf No.	Calf weight, lbs.	Water consumed (gal.) 12:20 p.m. to 12:35 p.m.	Temperature (°F.)						
				12:20 p.m.	12:50 p.m. (deg. F.)	1:05 p.m. (deg. F.)	1:35 p.m. (deg. F.)	2:10 p.m. (deg. F.)	2:55 p.m. (deg. F.)	3:30 p.m. (deg. F.)
Warm water (87 °F.)	1	600	3.5	105.0	104.5	104.6	105.0	105.0	105.1	105.6
	2	554	3.6	104.3	104.1	104.0	104.6	104.2	104.1	105.1
Cold water (60 °F.)	3	602	4.0	105.4	103.9	103.6	104.4	104.1	104.4	104.8
	4	621	4.0	104.6	103.0	102.9	103.2	103.2	103.6	104.1

THE TESTS SHOWED

Practical use of water is a definite aid in beef production

Water as a cooling agent has a number of advantages; it is cheap, easily available by ditch or pipeline, and has the highest heat capacity of any common liquid as well as the highest latent heat of evaporation. Several methods of using water for cooling livestock were tried.

Sprays

Five different experiments were conducted in which sprinklers or sprays were used in various ways. Wetting beef cattle with water definitely reduces their body temperature some 1.5° and their respiration rate some 20 or more respirations per minute. Animals have to be educated to the use of a shower by playing a garden hose over them. When shower stalls have been provided where they pass through from drylot to pasture, "boss" animals seem to take over and the other animals do not get sufficiently moist to be benefited.

Animals appear to receive more benefit from coarse sprays than from foggers. Although they enjoy the water and in most cases gain slightly more than the check animals, the increases in gain do not have the significance found in other methods of cooling. For four tests where weight-gain data are available, the average increase in daily gain has been 0.14 pound. Theoretically, water has many fine attributes as a cooling agent, but cooling animals by sprays has not proved too satisfactory in the tests conducted to date. So far, the only logical explanation for this is the rise in humidity which comes from the sprays themselves and from the evaporation of water from the surface of the cattle. Sanitation would also be a real problem if sprinklers were used on a large number of animals in a feedlot. Figures 18 and 20 show two methods of using sprays to cool cattle.

Cooling Shade Surfaces

Tests were run to compare two types of shade—one with a sub-roof of galvanized iron which was kept wet with water,

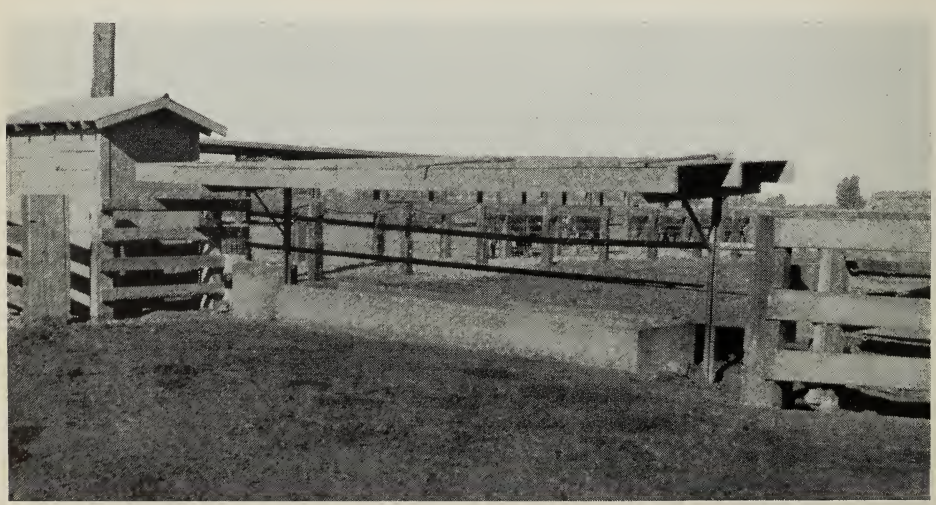


Fig. 27. A concrete drinking tank with shade. The shade should not be large enough to encourage cattle to stand near tank for shade.

the other with a sub-roof of burlap kept wet with a system of sprinklers (fig. 9). Instrument recordings showed these two environments to have a cooler surrounding, roof and ground, than did the check shade, but the increases in animal gain were not significant enough to justify the high construction cost; furthermore, the burlap sub-roof left much to be desired as to sanitation. Here again, humidity may have had an influence on the gains of the cattle.

Cooled Drinking Water

Much of the water used for drinking comes from the Colorado River. During the summer the temperature of drinking water from this source is about 90° F. Since the water was so warm, nine experiments were conducted to see if water cooled to 65° F by refrigeration would help the animals keep cool. Two of these tests were complicated by other factors, but seven tests gave an average increase in daily gain of 0.36 pound for the cool-water group; four of these experiments were significant at the 1 per cent level; one was significant at the 5 per cent level. The range ran from 0.19 to 0.50 pound increase in gain.

Tests were made with both 60° and 70° F water and resulted in no difference in gain between the two temperatures. Cooling of water by refrigeration may be too expensive for the average feedlot, but there are several inexpensive ways to provide cooler water for cattle.

Water pipes should be kept underground and not used as part of the corral. This does not cool the water from the ditch, but it does keep it from getting any hotter. Shade over the water tank will keep water 2° to 3° lower than that held in tanks in the direct sunlight. This shade should run east and west, shading the tank for most of the day, and should be just large enough to shade the tank. Larger shades sometimes provide enough shadow for a few of the "boss" animals who keep the others away from the water. Tanks with false bottoms that hold only 8 to 10 inches provide cooler water, since the water cooled by surface evaporation does not sink out of reach of the animals when it cools. Figure 27 shows one of these tanks. In this case the pressure system is shaded, which is also a help. Shallow tanks are easier to keep sanitary and do not leave much water in the corral when it is cleaned. Deeper tanks, however, have the advantage of providing water for a longer time if the water system should break down.

The tests have shown that cooler water is a definite benefit to cattle, so whatever can be done toward keeping water cooler should be a benefit. The reason for cool water increasing daily gains is not definitely known, but it does keep body temperatures a degree or two lower for several hours after a drink. Animals do not drink more cold water than warm; in fact, in most cases they drank a gallon or two less per day. Salt used with feed to increase water consumption did not result in greater weight gains.

Air has a complex influence on the comfort of animals. The evaporative exchange of heat between an animal and air is influenced by both rate of air movement and condition of air (temperature and humidity). Convective heat exchange is controlled by rate of air movement and the temperature difference between animal surface and air. Radiation exchange is affected indirectly by air movement and temperature because of the influence these have on animal surface temperatures.

Little is known of the vaporization rate of moisture from beef cattle. Studies with dairy cattle at the University of Missouri (Thompson, Yeck, et al., 1954) indicate that under conditions of increased air movement, convective cooling is primary. The use of water sprays and shower baths (page 34) was an attempt to increase the evaporative exchange of heat.

As long as air temperature is lower than the surface temperature of an animal, air has a potential convective cooling effect (page 10). The surface temperature of an animal increases with increasing air temperature but at a slower rate so that the temperature differential that controls convective cooling decreases as air temperature increases. For dairy cattle (Thompson, et al., 1954) this temperature differential is zero at an air temperature of about 103° F. When air has a temperature greater than this it then has a potential convective heating effect. To offset this decreasing temperature differential, when cooling is most needed, the velocity of the air can be increased. However, an increase in air velocity tends to reduce the animal-surface temperature and again reduce the temperature differential between air and animal surface. With a lower surface temperature there exists a greater potential for radiation exchange from the surroundings to the animal. With the greater wind velocity there exists a greater potential for evaporative cooling.

Even though the relationship between air and the several modes of heat transfer is complex, air can be used effectively for cooling beef cattle. Some of the best results of this investigation were obtained by lowering the air temperature and increasing its velocity over the animals.

Evaporatively Cooled Air

Animal heat loss can, of course, be increased by lowering air temperature and increasing air velocity, thus increasing the fraction lost by convection. Cooling air by water evaporation is economical and feasible in hot, dry climates. Most commercial evaporative coolers pass air through wetted excelsior pads. The sensible heat of air and unevaporated water is changed to latent heat of evaporation, thereby reducing the dry-bulb temperature of the air to a few degrees above the wet-bulb temperature. Gordon and Perry (1942) have described application of the evaporative or "desert cooler" to the air conditioning of homes in Cali-

Fig. 28. Three-sided 16 × 24-ft. shade cooled with 2500-cfm evaporative air cooler installed on south end. North end is open.

fornia. Tavernetti (1940) studied the cooling of poultry houses by this means. Desert coolers applied to cooling beef cattle pose a special problem under California methods of management, for the structure must be open enough for free in-an-out movement of the cattle.

In 1948, an evaporative cooler was used under a 16 × 24-foot shade, with the area enclosed except for the north side (fig. 28). The walls were of hay packed between woven-wire fencing nailed to both sides of 6 × 6-inch posts. The roof was aluminum sheets laid over boards, with a 3-foot layer of hay supported on woven wire beneath it for additional insulation. An evaporative cooler with a rated capacity of 2500 cfm was installed under the south end of the shade, near the roof line. A galvanized iron shade, 16 × 24 feet and 10 feet high, was used as a check on performance.

The evaporative cooler, usually operated from 9 A.M. to 5 P.M., provided approximately one air change per minute. Continuous records were obtained for air temperatures and relative humidities, inside and outside (four hot days, shown in fig. 29). The dry-bulb temperature of the air at the fan outlet was reduced 15° to 20° by the cooler, to about 5° above the wet-bulb temperature of the outside

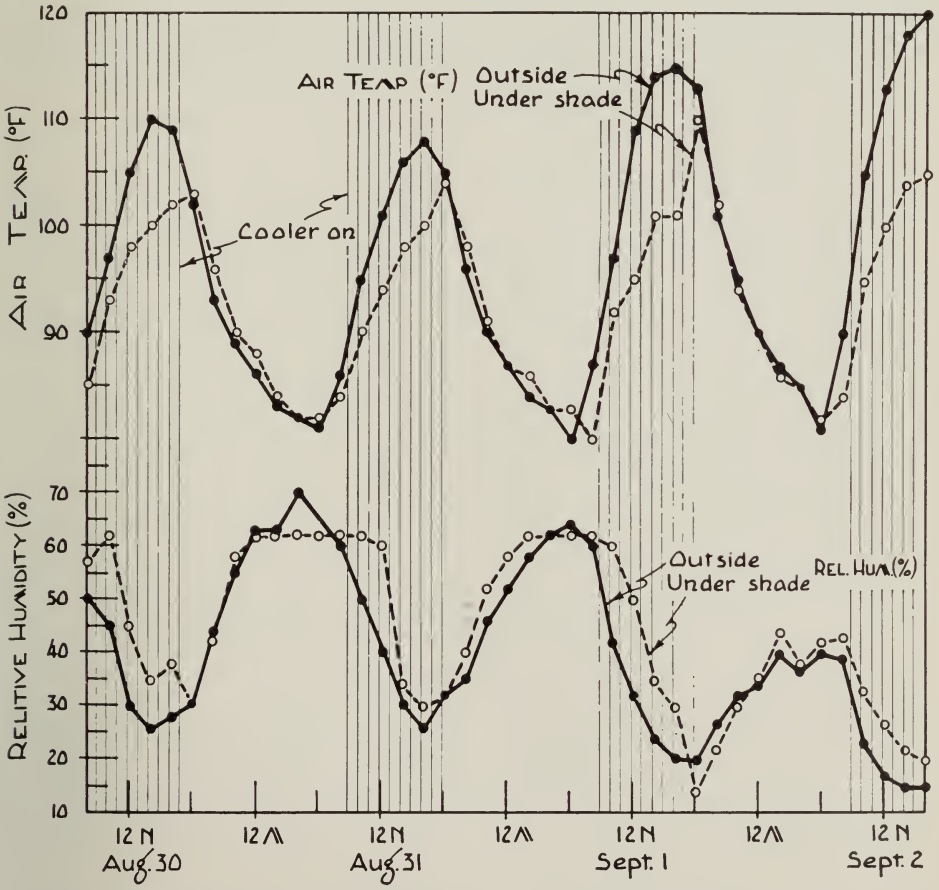


Fig. 29. Air temperature and relative humidity outside and inside of 3-sided shade cooled with "desert" cooler in 1948. Vertical grid indicates periods of fan operation. Recording instruments were located at center of shade, 3 feet above ground.

air. However, since this cooled air quickly mixed with the warm air under the shade and received heat from the walls and cattle, the inside temperature was rarely as much as 10° cooler than the outside temperature, and never more than 10° cooler. It will be noted in figure 29 that the greatest reduction in air temperature occurred at the hottest time of the day.

Fan-induced air motion within the shade increased heat loss by convection when the air temperature was below 102° to 105° F. (Above this temperature the surface temperature of a shaded animal may be below air temperature.) The air velocity was about 850 fpm at the fan outlet and 300 to 500 fpm at the shade center 3 feet above the ground. Near the shade walls and toward the open end, it varied between 50 and 100 fpm. The cattle preferred standing where the air velocity was greatest, which of course was also the region of lowest air temperatures.

Ten Herefords and four Brafords used in a 54-day feeding trial (July 28 to September 20) were divided into two groups equal in numbers and breed proportions: seven animals under shade constructed and cooled as described above, and seven under an uncooled, galvanized iron shade. Both lots received all the good alfalfa hay they would eat, in mangers outside the shade. During the last 27 days they received daily 1 pound of ground barley per head in addition. For the Herefords (429 pounds average initial weight) average daily gain per animal was 1.05 pounds under the cooled shade and 0.69 pound under the galvanized iron shade, a difference of 0.36 pound which may be attributed to the cooler air or to the increased air movement. The Brafords showed no significant difference in gains (table 12).

Both Herefords and Brafords entered the shade as soon as the cooler was started in the morning, leaving only occasionally to eat and drink, usually between 1 and 2 P.M. About 4 P.M. or later on extremely hot days, the animals would leave the cooled shade and lie in its shadow, where they were exposed to the cool sky, for greater radiation heat loss.

Air Cooled by Refrigeration

In 1953 a small building was constructed (14 × 16 feet) and insulated with bales of hay and building paper (fig. 30). A mechanical air-cooled refrigeration unit (about 3 tons) was used to cool this room and was set to cool it to 65° F. However, because of the high summer temperatures the room temperature usually only cooled down to 70° or 75° F. An electric clock started the cooler at 2 A.M., and at 6 A.M. the four 840-pound Hereford steers were put in the room and fed alfalfa hay. The ani-

Table 12—Comparison of weights and gains of Hereford steers cooled with a desert cooler

(July 28–September 20, 1948)

Type of shade	Number of Herefords	Average* initial weight (lb.)	Average* final weight (lb.)	Average daily gain (lb.)	Feed per† 100 pounds gain (lb.)
Galvanized iron roof	5	430	467	0.69	1230
Desert cooler	5	428	485	1.05	1158

* Average weight and gains are only for the Herefords since there was no significant difference between the 2 Brafords in each pen.

† Feed per 100 pounds of gain includes feed eaten by the Brafords.

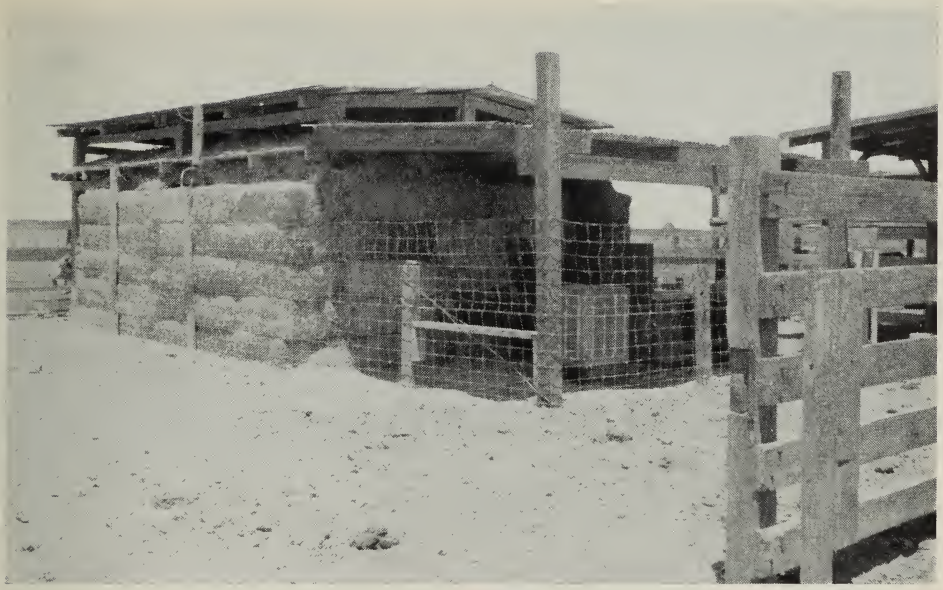


Fig. 30. Air-cooled shelter used for night cooling of four Hereford steers, Imperial Valley Field Station.

mals were left here until 10 A.M. when they were locked out of the house but had plenty of shade in the corral.

Previous observations had indicated that cattle will do well, even though daytime temperatures are 110° F or more, if they can cool off at night for a few hours with temperatures around 65° F.

This test ran from June 30 to September 22, and the cattle only gained 0.93 pound per day while the check steers gained 1.18 pounds. A hygrothermograph in the house showed the average temperature in the house to be 74° F and the relative humidity 59 per cent during the time the animals were in the structure. This is about the point where body temperature of cattle begins to increase. Although the cattle enjoyed the cool house, the capacity of the refrigeration unit was not large enough to cool the animals sufficiently to be of any benefit. Apparently the heat load imposed on the cooler by the four 840-pound steers was too much, as the temperature began to rise as soon as the animals entered the house.

Natural Air Movement

When the differences in daily gain were first noticed between cattle fed in heavy wooden corrals and those fed in wire pens, these differences were thought to be due primarily to the radiant heat load from the corral fences. Black-globe thermometer readings indicated heat loads of as much as 10 Btu per hr. per ft.^{2} of animal surface less in the wire pens, benefiting the animals about as much as lowering the air temperature 4° (comfort equation, Raber and Hutchinson, 1947). Since the air temperature was about 2° lower in the wire pens to start with, and with a lower heat load, the animals were in an environment that was in effect 5.5° to 6° less. Later data have shown that wire pens have greater air movement than wooden corrals, and mechanically increasing the air movement has proved to be very beneficial in increased daily gains of beef steers.

Differences in daily gains were first noticed in 1953 when, as a matter of convenience, one lot of 7 steers was moved to a wire pen at some distance

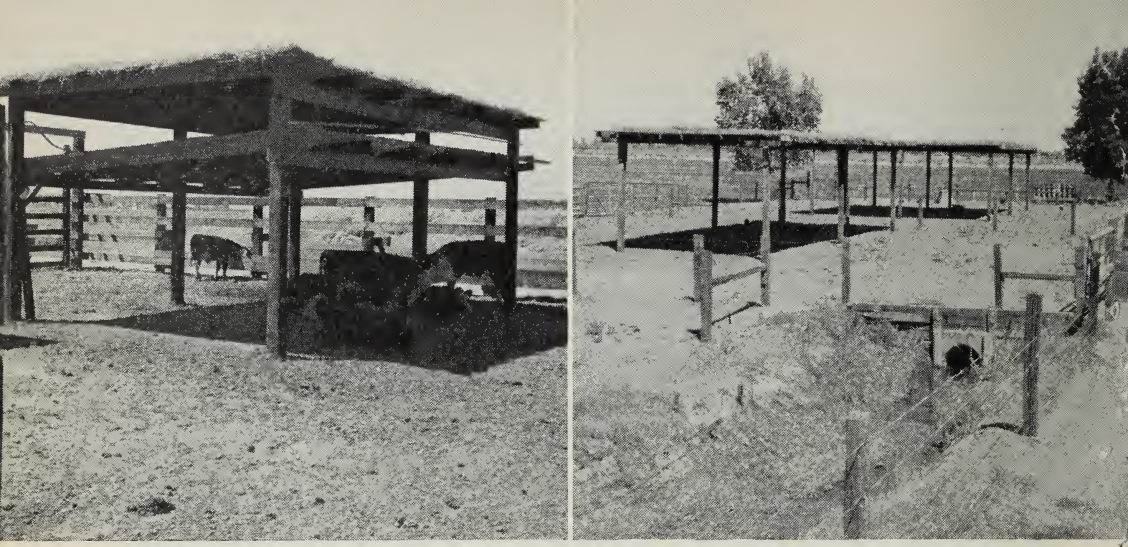
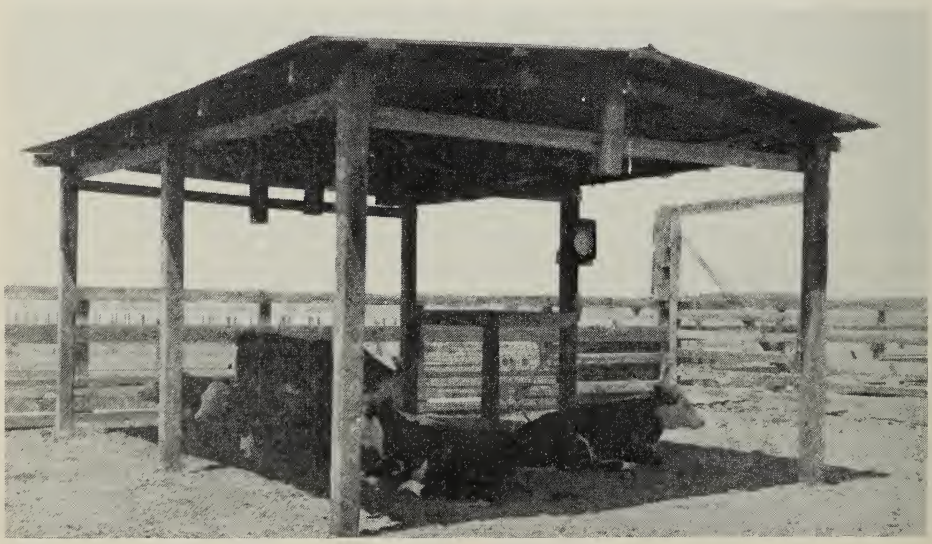


Fig. 31. Picture on left shows the construction of the main corral, while the right picture shows the wire pen used in these environmental studies.

from the main corral (fig. 31). It was not realized at the time that the difference in environment would be enough to affect gains. During the month of July these steers made a daily gain of 1.76 pounds, but when they were moved back to the main corral all animals lost a little or remained the same weight for the month of August. The month of September was cooler and all lots made good daily gains.

Five other animals, not included in this 1953 experiment, were fed hay and grain with warm water at the main corral, and it was difficult to keep them on feed; as soon as they were moved to the wire pen (July 28 to August 24) their food consumption increased, each consuming 11.2 pounds of concentrate per day, as compared to only 9.3 and 7.1 pounds for lots receiving cold water and warm water in the heavy wooden corral.

Fig. 32A. Shades and corrals used in the test. This picture shows aluminum shade in wooden corral.



Two groups of Hereford steers were fed in this wire pen during the summers of 1951 and 1952. Gains were 2.42 pounds for some rather thin steers averaging 800 pounds, and 1.79 pounds for some rather fleshy 1,000-pound steers. The dates of these tests were July 2 to September 12 and July 10 to September 3. Instrument readings, as noted above, indicated a comfort advantage for the wire pen due to differences in air temperature and velocity and to differences in radiation from surrounding surfaces.

An experiment was designed to check these observations and run during the summer of 1954. In the spring two wire pens, 35×60 feet, were constructed in an irrigated alfalfa field near the wooden corral. In each pen there was an 18×35 foot hay-covered shade. The wooden corral was 50×50 feet with an aluminum shade 18×35 feet. The floors of all three corrals were dirt. Each pen provided 90 sq. ft. of shade per animal, which was felt to be more than adequate. Views of the wood and wire pens and their shades are shown in figure 32. Circular concrete drinking-water tanks 30 inches high and 36 inches in diameter were installed in each pen. The tank in the wooden corral was not shaded during the first month, but was shaded during the remainder of the test. Shade was provided for the tank in the wire pen throughout the test. This tank had a false bottom, holding only 8 inches of water (28 gallons). There were 110 gallons of water in the tank in the wooden pen. The other wire pen had the cooling tower for drinking water, discussed on page 47. One wire pen and the wooden corral had a microweather station continuously recording air temperatures and wind velocities. The temperature-sensing elements for the recorders were installed near the centers of the corrals in two small shelters, painted white, with anemometers on top (fig. 5). This instrument shelter was about 30 inches above the ground.

Seven Hereford steers averaging 814 pounds were placed in each pen and fed a pelleted diet consisting of 35 per cent alfalfa hay, 15 per cent oat hay, 35 per cent barley, and 15 per cent molasses-dried beet pulp. During the first 28 days of the test both lots developed an appetite for the wooden mangers and corral fences, but with the addition of 1 pound

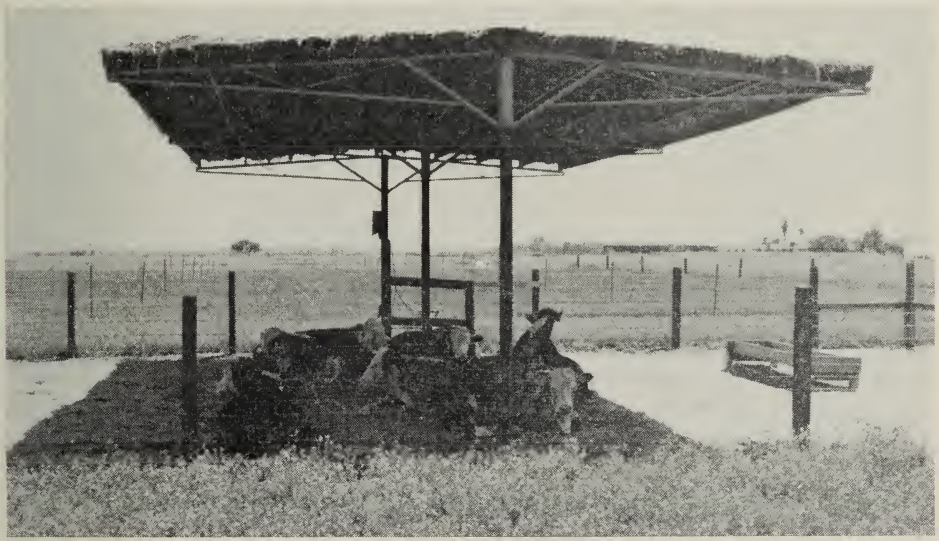


Fig. 32B. This picture shows a hay-covered shade located in a wire pen surrounded by a green alfalfa field.

of oat hay per day this tendency was eliminated.

Weather data for the summer of 1954 are presented in table 1. Recorded temperature extremes were 60° and 117° F. Temperatures fell below 70° F on 17 nights. The mean temperature for the 84-day feeding period was 90° F and the mean relative humidity was 39 per cent. There was one period of 15 days when the night temperature did not drop below 80° F.

Daily gains, food consumption, and economy of gain are shown in table 10. The animals in the wood corral had an average daily gain of 1.51 pounds while those in the wire corral made a gain of 1.94 pounds, and those in the wire corral with cool water 2.03 pounds. These differences between the wire pens and the wooden corral are significant at the 1 per cent level. The cattle gains in the wire pen with the cool water were not significant when compared to the daily gains of the animals in the other wire pen.

Average diurnal temperatures for the period of the experiment (June 24 to September 16) for an outside weather station, wooden corral, and wire pen, and the relative humidity at the weather station are presented in figure 33. Average temperature was 90.0° F at the outside weather station, 89.5° in the wood corral, and 85.7° in the wire corral. In the morning, temperatures at the wood corral ran a little higher than at the weather station, but were lower in the afternoon. Temperatures at the wire pen, from 7 to 9 A.M., were the same as the outside weather station, but were somewhat lower for the remainder of the day.

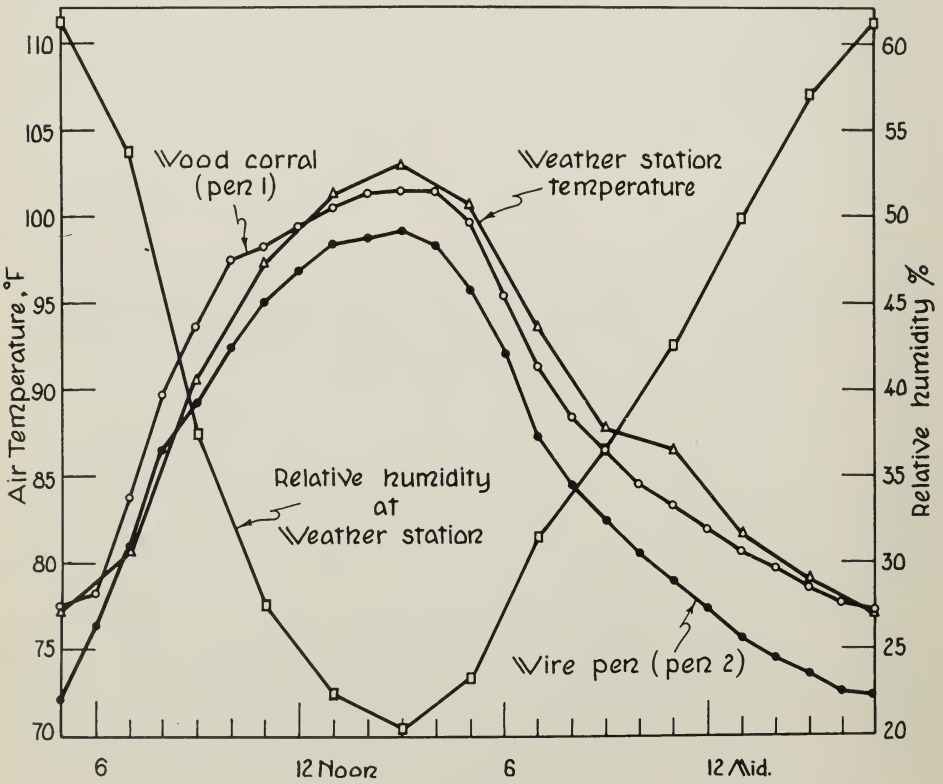


Fig. 33. Air temperatures in wood and wire corrals and at outside weather station. Relative humidity at outside weather station.

Wire-pen temperatures averaged 4.3° lower than at the weather station and 3.8° lower than in the wooden corral. Average relative humidity at the weather station ranged between 20 and 60 per cent but only 20 per cent during the hottest part of the day (usually around 3 P.M.).

Average diurnal wind velocity is presented in the upper section of figure 34. The wooden corral had an average wind velocity of 1.11 mph while the wire pen had 2.43 mph. The greatest difference usually came around 5 P.M., with an air velocity of 1.34 mph for the wooden corral and 3.36 mph for the wire pen, a difference of 2.02 mph. These records only cover the first two months of the test period, as the wind recorder broke in the wooden corral during the third month. Average wind velocity for the third month at the wire pen was 1.79 mph.

The animals in the wire pen had a cooler environment from lower radiation as well as from lower air temperature and greater air velocity. Radiation measurements at the center of the shadows, made with globe thermometers on August 28 and 29, indicated that the radiation heat load was less in the wire pen

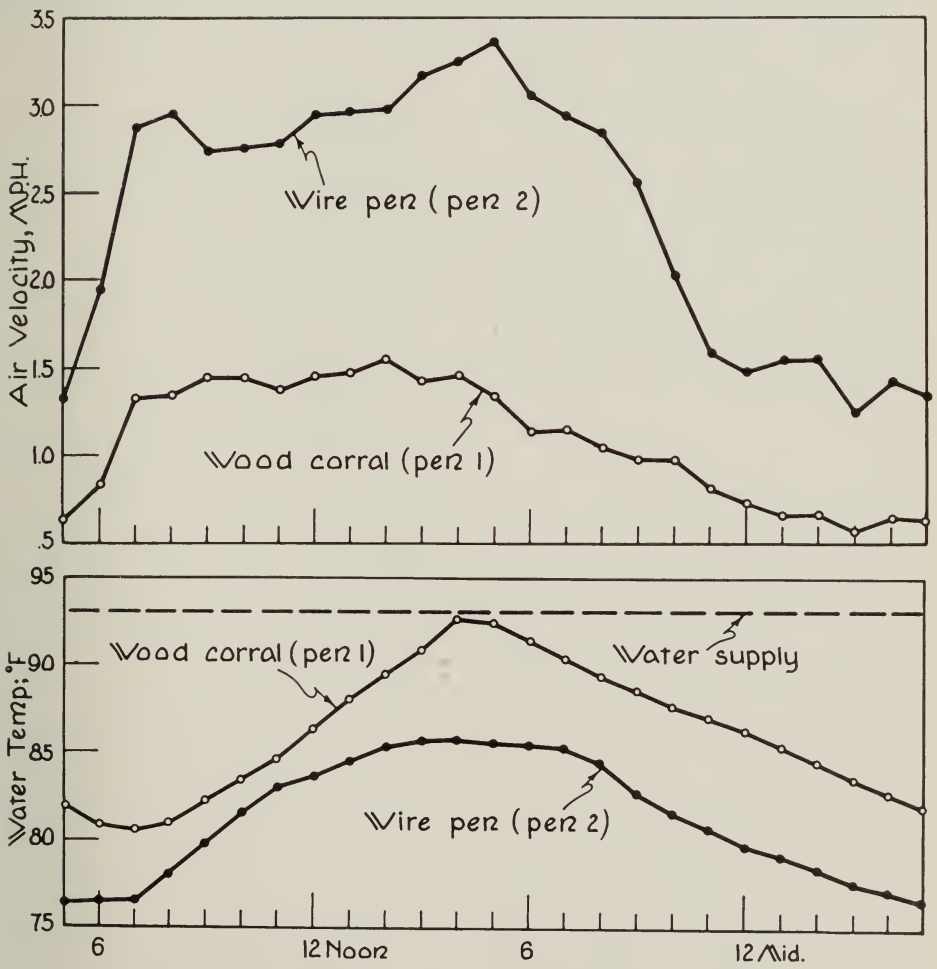


Fig. 34. Upper: Average diurnal air velocities in wood and wire corrals. Lower: Average diurnal drinking-water temperature in the two pens and temperature of water supply.

by as much as 9.5 Btu per hr, per sq. ft. of animal surface. Radiation and reflection from the wooden fence were high. At noon a horizontal reading with a directional radiometer pointed north indicated a radiation intensity of 212 Btu per hr. per ft.^{2} in the wooden corral, as compared to 163 in the wire pen.

If the radiation and air-temperature effects are combined into a single representative environmental temperature (average of mean radiant temperature and air temperature), then the representative environmental temperature in the wire pen was about 5° less. Similar comparisons of environment during the late summer of 1953 (but at a different location than the 1954 test) showed the environmental temperature in a wire pen to be 5.5° to 6° lower than that in a wooden corral.

Radiation observations were made rather late in the season on days when the maximum air temperature was only 97° F (as compared with a season's average of 103.6° F). It is probable that the effects of corral construction upon radiation heat load showed even greater differences during most of the test period.

The drinking-water temperatures for the two pens are shown in the lower section of figure 31. The wooden corral had an average daily water temperature of 86.3° F, while that of the wire pen was 81.4° F, and the wire pen with the cooling tower averaged 70° F. Tap-water temperatures did not vary much throughout the 24-hour period or through the period of the experiment, staying very close to 93° F.

Air movement with low humidity cools the drinking water by evaporation, and the cool water in a shallow tank remains available to the cattle because it cannot sink out of reach. However, part of the differences in water temperature shown here can be attributed to the shallow tank being located in a cooler environment (wire pen).

Weather during the summer of 1954 was cooler than average, and the humidity was a little lower because of an absence of summer thunder showers.

These experiments show definitely that proper equipment for cattle can reduce thermal heat load and increase daily gains significantly.

Mechanical Air Movement

Since there was a difference in air movement of 1.32 mph, between wooden and wire pens, and the difference in daily gain could be attributed to either increased air movement or to a reduction in radiation heat load, it was felt advisable to study the cooling effect of wind on cattle by mechanically increasing the air movement.

During the summers of 1955 and 1956 feeding trials were conducted with Hereford steers for 70-day periods, from July 6 to September 14, 1955, and June 27 to September 5, 1956. Seven steers were fed in each of two similar pens, except the pen without the fan had only five steers in 1956. Two steers were lost to the experiment at the very beginning. The average weight of animals at the start of the test was 670 pounds in 1955 and 651 pounds in 1956. Both pens were about 50 × 50 feet, and each had a 17 × 32-foot shade that was 10 feet high (about 78 sq. ft. of shade per animal). The drinking water was uncooled (about 87° F). The animals were fed twice daily and were given all they would clean up between feedings.

One pen each year served as a check pen—that is, a pen with no artificial movement of air through it. For the second pen, a 42-inch barn-ventilating fan (17,000 cfm capacity) was mounted on top of the 6-foot board fence along the side of the corral from which the prevailing wind blew (fig. 35). In 1955 the fan ran 12 hours during the day the first 21 days, then continuously for the remainder of the test. In 1956 the fan ran continuously. The center of the air

Fig. 35. This 42-inch barn-ventilating fan (17,000 cfm capacity) was used to cool the cattle by convection.

stream was directed down into the corral at about the center of the shade. Air velocity on the animals at the center of the shade was about 350 fpm or about 4 mph. In 1955, at the center of each pen, at animal level, there was a wire pen enclosing a small weather station (fig. 5). These were not used in 1956. These portable weather stations recorded the air temperature, air velocity, relative humidity, and black-globe thermometer temperatures at animal level.

As shown by the chart, (fig. 36) the distribution of air was quite good and air movement was increased over practically the entire pen. When these air-velocity readings were made, the average velocity of air in the check pen was 50 fpm. Animals naturally stayed under the shade most of the day and so were exposed to a good breeze all day. Since the weather records were not kept for the two pens in 1956, the records reported are for the 1955 test, but weight gains, feed consumption, and weather station records are reported here for both years.

Over the entire 70-day period (1955) the air velocity at the center of the shade of the check pen was 55 fpm (0.63 mph). In the fan or windy pen it was 325 fpm (3.7 mph), while at the weather station the air movement was 1.75 mph. Figure 37 shows the diurnal wind velocity for these three locations. There was no difference in relative humidity between these two pens; the relative humidity at the weather station was 46.4 per cent. The average air temperatures in the two pens and at the weather station, over the entire period, were 87.5°, 88.8°, and

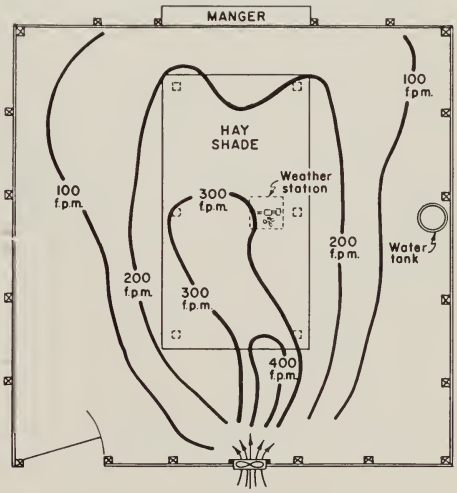


Fig. 36. Air velocity distribution in windy pen, Imperial Valley Field Station, 8:30 a.m., June 30, 1955.

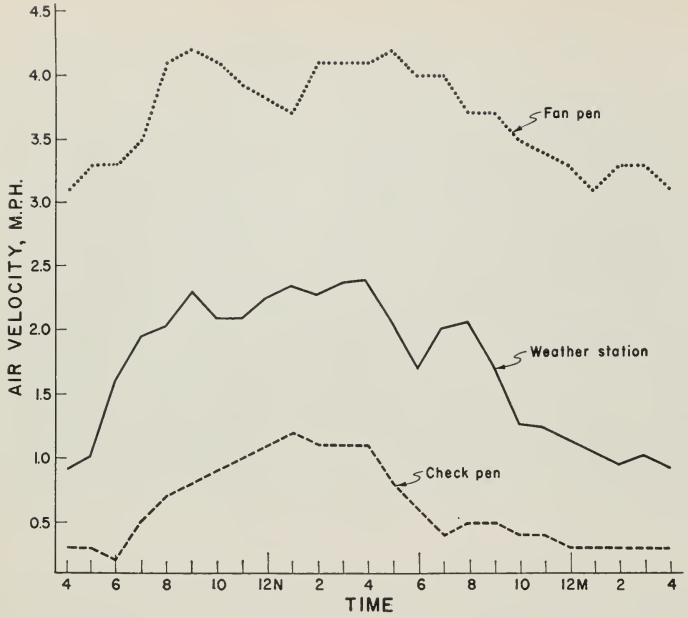


Fig. 37. Diurnal air velocity in the fan pen and the no-fan pen and at the weather station.

90.3° F respectively for check, windy pen, and weather station. Figure 38 shows these differences for the three locations. In the morning there was very little difference in air temperature, but from noon until approximately 8 A.M. differences of 1° to 5° are noted, and they are lower at the corral in the check pen than at the weather station. These lower temperatures are more marked during the hours of darkness. The temperature in the fan pen was only about 2° lower than at the weather station.

On August 11, 1955, and September 11, 1956, four Hereford calves were used to check the cooling effect a fan has on body temperatures. Air temperatures at 2 P.M. were 103° and 106° F, humidity

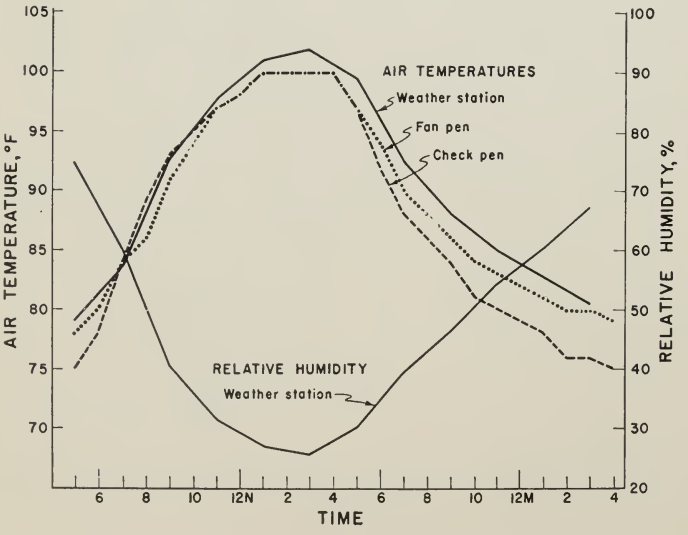


Fig. 38. Air temperature, relative humidity in the fan pen, in the no-fan pen, and at the weather station.

26 and 18 per cent respectively. At about 9:00 A.M. all four calves were tied in the shade without any air movement, and body temperatures were taken at 9:30 A.M. Right after this two calves were moved under the shade where the fan was blowing, and body temperatures were taken as shown in table 13. Both shades and pens were identical. Body temperatures were definitely lower for the calves under the fan.

During the time the body temperatures were being taken in 1955, skin temperatures were also measured. Each skin-temperature figure shown in table 14 is an average of six readings. Air velocity during this test averaged 400 fpm in the windy pen and 20 fpm in the pen without the fan.

As long as air temperature is lower than the surface temperature of an animal, wind has a potential convective cooling effect. If, however, the air is warmer than the surface, the effect re-

Table 13—Body temperature differences of Hereford steers with and without a fan*

August 11, 1955†

	Calf No.	Calf weight	Body temperatures, °F.					
			9:30 a.m.‡	10:00 a.m.	10:45 a.m.	12:15 p.m.	2:30 p.m.	
Fan	1	602	104.3	104.0	103.7	103.8	104.4	
	2	621	104.2	104.8	104.2	103.9	104.2	
Average	...	...	104.25	104.40	103.95	103.85	104.30	
No fan	3	600	104.6	104.8	104.7	105.6	105.8	
	4	554	103.8	104.6	104.8	104.8	105.1	
Average	...	...	104.20	104.70	104.75	105.20	105.45	

September 11, 1956†

	Calf No.	Calf weight	Body temperatures, °F.					
			9:30 a.m.‡	10:00 a.m.	11:00 a.m.	12:00 noon	1:00 p.m.	2:00 p.m.
Fan	5	754	103.8	104.4	104.8	104.4	104.4	104.6
	6	692	102.9	103.6	103.8	103.3	103.5	104.3
Average	...	...	103.35	104.00	104.30	103.85	103.95	104.45
No fan	7	587	102.4	103.4	103.0	103.7	104.0	104.1
	8	690	104.4	106.2	105.8	105.2	106.2	106.1
Average	...	...	103.40	104.80	104.40	104.45	105.10	105.10

* Air movement averaged around 400 fpm in the fan pen and about 20 fpm in the no fan pen during the tests.

† August 11, 1955, 2 p.m. air temperature 103°, humidity 26 per cent; September 11, 1956, 2 p.m., air temperature 106° humidity 18 per cent.

‡ Right after their body temperatures were taken at 9:30 a.m. two calves were moved to the shade in the fan pen, the other two stayed under the shade in the no fan pen.

Table 14—Skin temperature difference of Hereford steers with and without a fan

(August 11, 1955)

Time	Air temperature °F.		Air velocity (ft. per minute)		
	*	†	20 (°F)	400 (°F)	Difference (°F)
9:50 a.m.	92.9	92.5	98.9	96.1	2.8
10:30 a.m.	94.3	95.6	102.6	96.8	5.8
12:30 p.m.	97.0	98.4	102.7	101.2	1.5
2:10 p.m.	99.0	103.5	104.4	101.8	2.6

* Air temperature in low air velocity pen.
† Air temperature in high air velocity pen.

Table 15—Cooling effect of a fan on Hereford steers

(July 6–September 14, 1955)
(June 27–September 5, 1956)

	1955		1956	
	Fan	Check	Fan	Check
Number of animals	7	7	7	5
Av. initial weight (lbs.)	669	669	645	657
Av. final weight (lbs.)	831	759	813	788
Av. daily gain (lbs.)	2.32	1.29	2.40	1.87
Av. daily feed (lbs.)				
Barley	5.07	4.23	4.65	4.73
M.D.B.P.*	2.33	1.92	2.32	2.37
Alfalfa hay	12.07	9.12	9.86	9.07
Oat hay	1.94	1.91	2.35	2.19
Total	21.41	17.18	19.18	18.36
Feed per 100-lb. gain				
Barley	219	327	193	253
M.D.B.P.	100	149	97	127
Alfalfa hay	521	706	410	485
Oat hay	84	148	98	117
Total	924	1330	798	982

* Molasses dried beet pulp.

verses so that there is potential convection heating from wind. Studies in chambers at the University of Missouri have shown that the surface temperature of dairy cattle increases with an increase in air temperature, but at a slower rate so that the surface temperature is always above air until both come together at about 103° F. Whether this 103° F holds good under natural conditions is not known, but there could be a variation from this point depending on relative humidity, velocity of air movement, and the amount of moisture lost through the skin of cattle. Tables 13 and 14 show that both body temperatures and skin temperatures of the calves were lower in the pen where air velocity averaged 400 feet per minute.

Water consumption during these two years did not vary much. Fan-pen animals in 1955 and 1956 drank 13.8 and 11.9 gallons per head per day, while the low-air-movement-test animals drank 12.4 and 12.2 gallons respectively.

Weather data for the test periods of 1955 and 1956 are shown in table 1. Although the mean temperature of 90.3° F in 1955 was not the highest during the 10 years of these tests, the average minimum of 78.3° F was higher than any other year. Only five nights had a minimum temperature less than 70° F. In 1955, one of the more humid years, the mean humidity was 46 per cent. Average maximum, average minimum, and mean air temperatures for 1956 were the lowest during the 10 years of testing. Mean relative humidity was 36 per cent, was close to the lowest of the 10 years. There were 21 days in the 1956 period with night temperatures lower than 70°F. The average daily gain for the animals in the check pen in 1955 was 1.29 pounds per day per animal, and they consumed 1,330 pounds of feed for each 100 pounds of gain. Animals exposed to the additional wind from the fan gained 2.32 pounds, and it took only 924 pounds of feed per 100 pounds of gain. In 1956 the differences were not as great; the check pen gained 1.87 pounds per head per day and the fan group gained 2.40 pounds. Economy of gain for the fan pen and check lot was 798 and 982 pounds respectively. Both years' differences were significant at the 1 per cent level. The feed intake of the fan pens was higher than the check pens during both years (table 15).

Animals were weighed every 14 days in 1956, but the weight gains and air temperature do not show much correlation. However, the humid weather in 1955 no doubt raised the night temperature and probably accounts in part for the very low daily gains of the check-pen animals. Lower temperatures and lower humidity in 1956 probably are factors in higher daily gains of the animals in the check lot.

Air movement can be increased in two ways. The first method is to allow the natural air currents and wind free access to the corral area by constructing the pens with wire, cable, sucker rods, pipe, etc. The second method is to use fans to increase the air flow around the animals. Both have given a larger increase in daily gain than most other cooling methods so far tested.

Natural Air Movement

Natural air movement can be increased by more than 1 mile per hour in the Imperial Valley by proper corral construction. One test showed an increase of 0.43 pound in daily gain when the animals in a wire pen were compared to animals in a wooden corral. Figure 39 shows this airy type of construction. Working corrals should be built with wood, since there is enough stretch in wire and cable to allow animals to escape if they become crowded and excited.

Mechanical Air Movement

Mechanical air movement by the use of fans has been tested two summers; the fan resulted in an increase in daily gain of 1.03 pounds the first summer, and 0.53 pound the second summer. Both pens used in the test were built of wood.

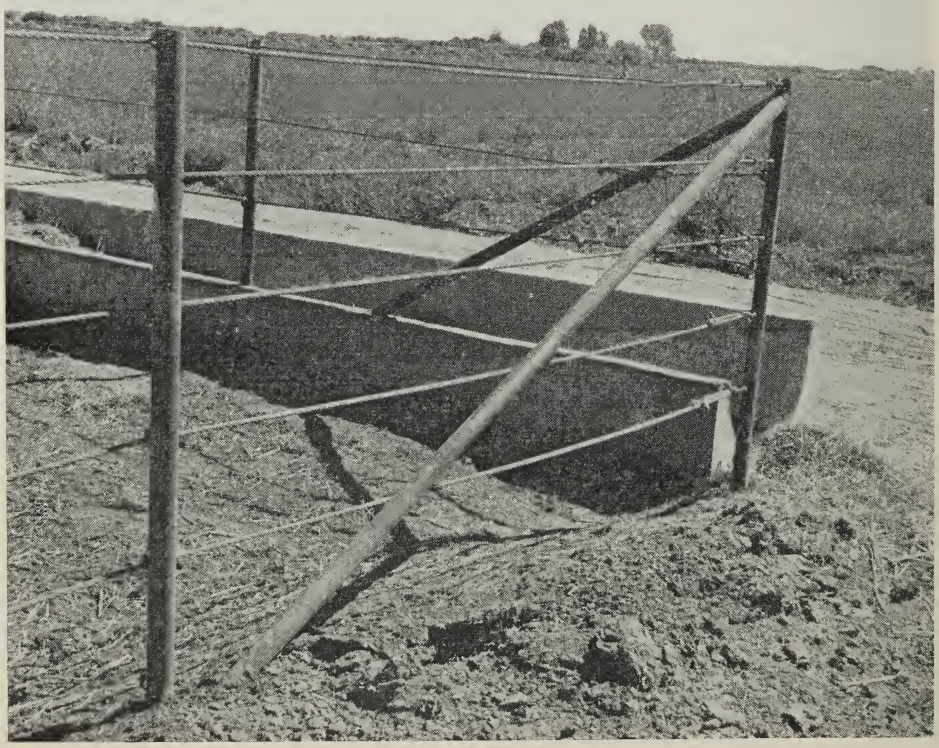


Fig. 39. Fence corner showing one type of cable corral construction.

The air movement in the pen with a fan averaged 3.7 mph, while that in the check pen averaged 0.63 mph (air movement checked first year only). The fan ran continually and was placed on the south side of the corral so as to assist the prevailing wind (fig. 35).

Further work needs to be done to determine if the fans need to be run only part of the day, the differences in gain a fan will make in a wire or cable corral, and the velocity of air movement most effective for keeping the animals cool.

Recent studies by Kibler and Brody (1950) have shown that European cattle lose a considerable amount of water through the skin even though they are not classified as sweating animals like the horse or man. Increasing the air movement around the cattle may facilitate the evaporation of this skin moisture which would carry away excess body heat. Several tests in which body temperatures were taken of animals under a fan and cattle without a fan have shown the ones with the fan to have a lower body temperature. This type of cooling seems to be quite effective.

Cooling Air by Evaporation

A "desert cooler" under a shade with three sides enclosed (fig. 27) was tested with Hereford and Braford beef cattle. The Brafords did not show a significant difference in gain, but the Herefords under the cooled shade gained 0.36 pound more than the check animals. The increase in gain was good, but the cost of construction and maintenance of shades of this type and the cost of the "desert coolers" is higher than some other cooling methods tested. Temperatures in the shed were rarely less than 10 degrees cooler than the outside air temperature. As later experiments have shown, the increased air movement may actually have been of more benefit than the 10° cooler air.

RADIATION

An animal is exposed to radiation from everything "within sight." The sky is an important source of radiation because it is so large. Parts of the sky, however, are cooler than an animal's surface and may be used advantageously as a cold sink to absorb radiation from an animal. Corral fences, because they are so close, influence the radiant heat lost or gained by the animal. The ground surrounding an animal is important both because it is close to the animal and is such an extensive source of radiation. These three surfaces—sky, corral fences, and surrounding ground—are nearly always "within sight" of the animal, so they are potentially important in influencing the radiation heat load on an animal.

North Sky

Directional radiometers provide a means of obtaining the radiation intensity at the surface of the earth from areas of the sky. Many traverses over the sky, from horizon to horizon, with a Gier directional radiometer indicate that azimuth orientation has little effect upon sky radiosity throughout the hot part of the day if the instrument opening receives no direct-beam energy from the sun, and if the sky is free of clouds. Angle of elevation above the horizon is important—an angle of 60° is usually the coldest.

In figure 40 a series of traverses with the directional radiometer in north-south and east-west orbits is shown for three different times on a cloudless day.

At 12 noon, when the radiometer target was 60° above the north horizon, the observations indicated the lowest sky radiosity. This area had a somewhat higher intensity at 10 and 2 o'clock. The same inference can be drawn from the east-west traverse, shown in the lower section of the figure. To cool a building by direct long-wave radiation to the sky, it would seem desirable to have all openings designed to have the greatest shape factor or seeing angle with respect to this area in the north sky about 60° above the horizon.

By using an emissivity for the sky of 1.0, the effective sky temperatures can be calculated. In figure 41 a series of 116 north-sky temperatures, observed with the Gier directional radiometer, has been plotted against air temperatures obtained simultaneously 42 inches above the ground. All observations were made between 10:00 A.M. and 5:00 P.M. on cloudless days (less than 10 per cent cloud cover), during the months of July to September. A linear regression curve has been fitted to these points. Its equation is: $t_s = -81.9 + 1.5\ t_a$, where t_s is the temperature of the sky and t_a the temperature of the air. A difference of about 28° between air and sky is available as a cooling sink at an air temperature of 100° F and of about 22° at 110° F.

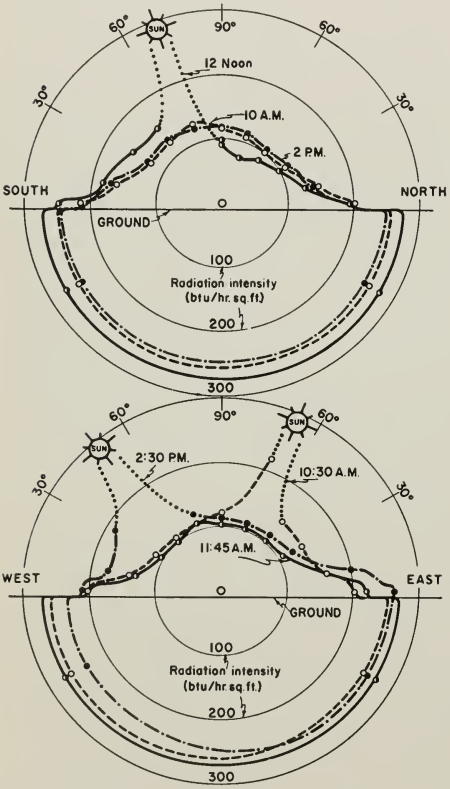


Fig. 40. Traverses of Gier directional radiometer in north-south (top) and east-west (bottom) directions.

The extent of cloud cover is the main factor controlling north-sky temperatures in the Imperial Valley. Data obtained from the Naval Air Station near El Centro indicate that during the hottest month, August, there were at least 15 days, throughout the period of 1949 to 1954, which averaged less than 10 per cent cloud cover at 2:00 P.M. It has been observed also that even when the south hemisphere may be fairly cloudy, the north sky may be clear because the clouds appear to form in the area towards the Gulf of California.

The large number of cloud-free days indicates a fairly reliable sink for radiation cooling, which should be exploited in the design of livestock shelters for hot climates.

Corral Materials

In the section "Natural Air Movement" (page 66), results of feeding trials were shown to indicate that animals in a corral enclosed by a wire fence gained more rapidly than animals in a corral surrounded by a heavy wooden fence. This greater rate of gain was attributed to a more comfortable environment in the wire-fence corral. The better environment within the wire-fence corral was due to: (a) a lower air temperature, (b) greater wind velocity, and (c) to less radiation in the pen. Just how much each of these factors contributed to the test results is unknown. In tests previ-

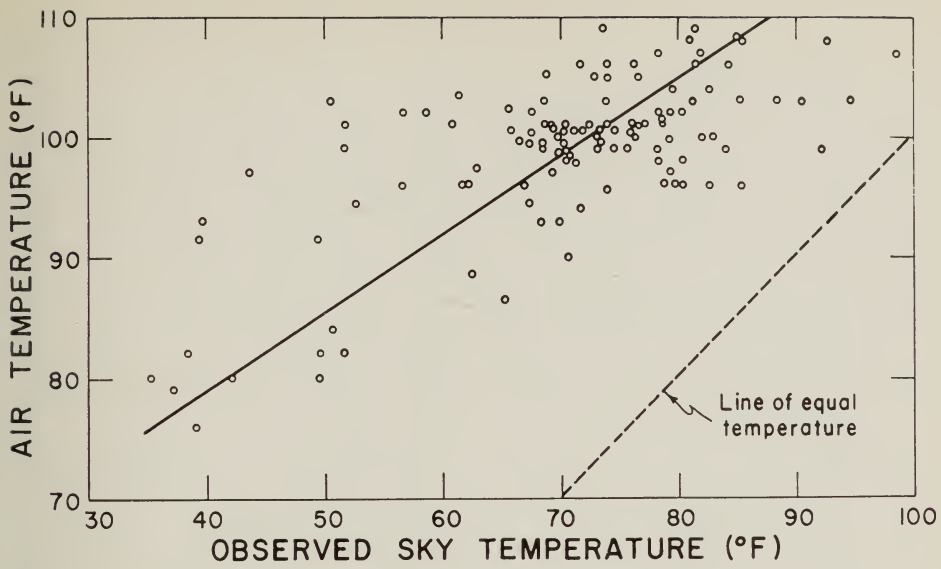


Fig. 41. Relation of air temperature at ground to effective north sky temperature 60° above horizon.

ously described, wherein the effect on animal weight gains of each of these three factors was considered separately (air temperature page 55, wind page 52, and radiation page 67), the benefits from wind were greatest, and from lower radiation, least. However, this should not be considered as an evaluation of the contribution each of these factors made in improving the climatic environment. The levels of differences between the control and test pens, for each of these factors, were unrelated, making comparison difficult.

It is somewhat more difficult to comprehend and measure radiation differences between two locations than wind velocity or air temperature differences. For this reason a detailed study was made in 1953 to investigate the radiation difference between wire-fence and wooden fence corrals. Six-inch black-globe thermometers were kept at the center of the shadows of the shades in two pens shown in figure 31. These were used to measure the radiant heat load to which an animal standing in that spot would be exposed. Radiation measurements were made with a directional radiometer to determine the intensity of energy radiated from different sources and objects in and around the wire-fence and wooden fence corrals. The curves of figure 42 show that the radiant heat load was less in the wire-fence corral—at times as much as 10 Btu/hr. ft.^{2} less. Also, the air temperature in the wire-

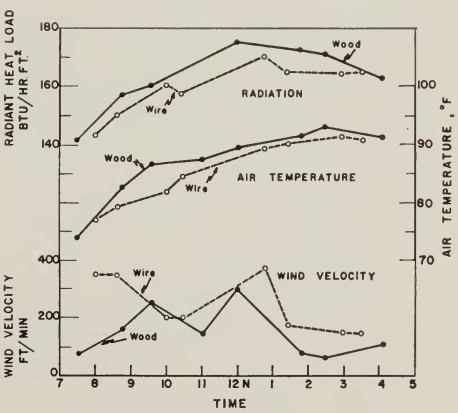


Fig. 42. Comparison of radiation, air temperature, and air velocity within the wooden-fence and wire-fence corrals, August 31, 1953.

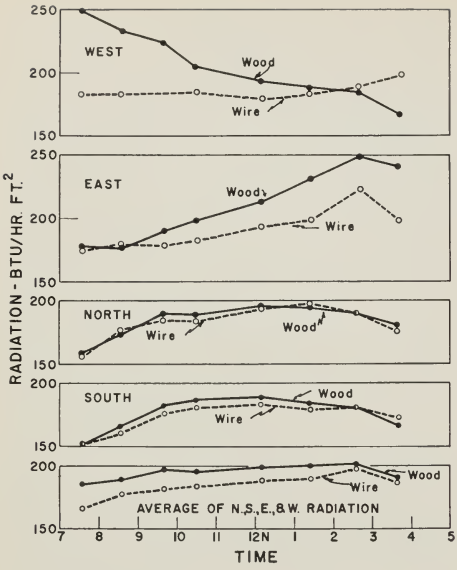


Fig. 43. Comparison of radiation from four directions in the wooden-fence and wire-fence corrals, August 31, 1953.

fence corral was less, averaging about 2° lower.

Radiation within the two corrals was also studied by taking a series of readings with a directional radiometer. With the receiver of the radiometer at a height of 24 inches and at the center of the shadow of the shade, a series of horizontal readings was taken to determine the effect of the corral material on the radiation coming from each direction. The results of one series of reading is shown in figure 43. During most of the period shown there was less radiation, in every direction, from the wire fence. During the morning the radiation from the wooden fence on the west was highest; in the afternoon it was highest from the wooden fence on the east. The position of the sun affects the amount of energy radiated from the boards—the boards became hotter, and more solar energy was reflected from them, as the sun became more normal to the boards. This was why the west boards radiated more in the morning and the east boards radiated more in the afternoon.

Reflectivity of the boards for solar energy was determined by measuring the quantity of solar energy irradiating them and the amount given off by them. These measurements were made with a solarimeter selective for wavelengths below 3 microns. Reflectivity of the boards was found to vary from 54 to 90 per cent, with an average value of 70 per cent. Such high reflectivity makes the board fences good potential heat sources. Solar-energy reflectivity of the ground was found to be about 47 per cent—lower than for the boards. This 47 per cent reflectivity would represent the reflectivity of the wire fence comparable to the 70 per cent reflectivity of the boards because animals inside a wire enclosure would be exposed to ground instead of the wooden fence. The high reflectivity of the ground inside the corral probably accounts for the greater radiation from the south fence (ground reflection re-reflected by the boards) even though the south boards were in the shadow of the sun.

The horizontal directional radiometer readings of figure 43 include radiation from the spaces between the boards, as well as from the boards themselves. The actual radiation from the boards, and from the spaces between the boards, was measured in a separate series of observations. The radiation from the boards was found to be considerably greater than the radiation from the spaces between the boards. The spaces would represent the effect of a wire fence because the actual radiation from the wire itself would be insignificant.

The corral-fence material actually does have an influence on the amount of radiation an animal in the corral receives. To reduce the radiant heat load on an animal a wire or cable fence should be used for penning animals.

Surrounding Crops

Ground temperature and radiation are important to the problem of animal com-

fort in warm climates. The flat-plate radiometer is an instrument that measures the total radiant energy falling on it from the hemisphere above. Measurements with this instrument facing both upper and lower hemispheres indicate that energy from the lower hemisphere may be as much as 40 to 60 per cent (ratio of lower hemisphere radiation to upper, table 16) as great as from the upper hemisphere, depending on the type of ground surface. The lower hemisphere radiation is comprised of low-temperature radiation, due primarily to the temperature of the ground surface, and reflected energy influenced by the radiation characteristics of the surface. Table 16 indicates some of the characteristic differences between unvegetated ground and alfalfa.

Lower hemisphere radiation was considerably less over the alfalfa field than over bare ground. The solarimeter measures only the short-wave energy between 0.295 and 3.0 microns. When the solarimeter is faced down it measures lower hemisphere short-wave energy only and, consequently, only energy reflected from the ground surface. A comparison of the incoming short-wave energy from the lower and upper hemispheres indicates the reflectivity of the ground surface. Table 16 shows that the reflectivity of the alfalfa is considerably lower than that of the bare ground. Over two adjacent 200-ft.-square plots the air temperature over alfalfa averaged 5° lower at mid-day than over plowed ground. At this same time the lower hemisphere radiation from the alfalfa was 30 per cent of the upper hemisphere radiation, and from the plowed field 40 per cent.

While it would be impractical to maintain green vegetation under and immediately adjacent to an animal shade, except while pasturing, it may be possible to increase an animal's comfort by selection of the proper type of unvegetated ground surface. Ground surfaces vary in temperature by reason of differences in thermal conductivity, density, and other characteristics. Measurements with a touch thermocouple in the Imperial Valley in August, 1947, showed a variance in ground-surface temperatures between areas only a few feet apart. At 11:00 A.M. when air temperature was only 89° F, the following temperatures were observed in the sun:

Hard ground, tramped by cattle....124°F
Hard ground, in road.....129°F
Soft ground, not tramped by cattle..132°F
Dry rotted manure in feed lot.....148°F

Table 16—Upper and lower hemisphere radiation over bare ground and over an alfalfa field as measured with a flat plate radiometer (total radiation) and a solarimeter (short wave radiation), Imperial Valley, 1954

Time	Upper hemisphere radiation, Btu/hr./ft²		Lower hemisphere radiation Btu/hr/ft²				Reflectivity, per cent	
	Total	Short wave	Total		Short wave		Ground	Alfalfa
			Ground	Alfalfa	Ground	Alfalfa		
9:55 a.m.	409	253	259	201	94	68	37	27
10:10 a.m.	411	282	268	199	79	66	28	23
1:00 a.m.	447	272	277	198	62	25	22	9

Table 17—Surface temperature observations, Davis, California, July 22, 1949

Time	Air	Loose loam	Grass		Clover		Stubble	Blacktop	Concrete	Gravel
			Over	Under	Over	Under				
11:30 a.m.	79.0	134.9	108.5	110.4	93.2	94.2	127.6	117.8	113.1	126.8
2 p.m.	89.2	141.4	106.6	105.6	90.4	88.2	121.5	120.1	119.0	122.3
4 p.m.	93.5	122.5	94.9	98.9	88.5	78.8	105.9	109.1	109.5	109.7
7 p.m.	72.6	86.2	69.5	71.0	65.3	65.6	70.4	86.6	86.5	85.9
9 p.m.	63.9	70.9	61.4	63.4	60.8	60.4	64.6	74.6	76.7	68.9

All temperatures °F. Observations made with touch thermocouple. "Over" observations near top of growth; "Under" observations are of upper soil surface.

During the summer of 1949 temperatures of several types of surfaces were measured (table 17) to show the great variation that can be expected.

During the summer of 1951 two identical $12' \times 12'$ portable shades were located in separate fields, one in an alfalfa field and the other in a plowed field to determine the effect of ground cover on environment. Black-globe thermometers were kept at the center of the shadow of each shade, at a height 12 inches above ground, to measure the radiant heat load at each location. Additional black-globe thermometers were located in the sun over each field.

The radiant heat load is an integrated measure of the effect of radiation from each part of the surround, sky, shade, horizon, unshaded ground, and shadow upon the total radiation the globe thermometer receives. The radiosity (includes both temperature radiation and reflected energy) from each part of the surround was measured with a Hardy radiometer. These values, for one day, are shown in table 18.

The cloudless sky is the coolest part of the surround and has the same radiosity with respect to both shades. The radiosity for the other four parts surrounding the shade over the plowed field is greater than for those surrounding the shade over green pasture, with the exception of the horizon. The radiosity of the horizon would be expected to be about the same over both fields because it includes trees, etc., that are equally on the horizon of both shades. The influence of these greater radiosities is reflected in the higher radiant heat loads over the plowed field as determined from black-globe thermometer measurements (table 19).

A "low-temperature" ground cover will help to reduce the magnitude of this source of heat. Also, ground temperature influences the temperature of the air over it, so it should be as low as possible; this is evident in the air temperatures over

Table 18—Values of radiosity determined with a Hardy radiometer, El Centro, September 11 and 12, 1951

Time	Sky	Shade		Horizon		Hot ground		Shadow	
		Over grass	Over dirt	Over grass	Over dirt	Grass	Dirt	Grass	Dirt
9/11/51									
10 a.m.	134.4	161.3	163.2	169.0	165.3	187.1	201.3	148.9	154.7
11 a.m.	139.0	162.9	170.6	167.4	178.3	200.0	212.8	150.5	161.9
12 noon	138.6	165.7	174.2	175.3	178.8	201.7	214.3	153.4	163.2
1 p.m.	138.7	165.7	173.1	170.7	175.6	195.5	209.0	154.9	164.4
2 p.m.	136.6	163.6	169.7	171.3	174.7	193.3	205.8	154.3	164.2
3 p.m.	144.8	164.0	167.9	168.8	166.9	178.6	185.1	155.3	162.8
6 p.m.	122.5	145.3	149.0	136.4	135.9	139.2	144.3	143.5	147.4
9/12/51									
1 a.m.	104.4	123.7	128.1	115.5	118.0	117.5	121.9	121.8	130.4
7 a.m.	120.9	142.4	144.2	136.8	135.6	144.8	150.9	127.8	131.1

All values for radiosity are Btu/(hr.) (sq. ft.).

Table 19—Radiant heat load determined from black globe thermometer readings, El Centro, September 11 and 12, 1951

Time	Air temperature °F.		Radiant heat load under shade Btu/(hr.) (sq. ft.)		Radiant heat load over open field Btu/(hr.) (sq. ft.)	
	Grass	Dirt	Grass	Dirt	Grass	Dirt
9/11/51						
10 a.m.	85.0	85.5	153.5	156.2	238.4	254.7
11 a.m.	84.0	86.0	159.5	166.4	248.1	251.6
12 noon	85.5	85.5	156.3	170.0	230.2	244.4
1 p.m.	86.0	86.5	156.3	165.0	251.8	263.3
2 p.m.	86.5	88.0	157.1	158.5	239.0	257.0
3 p.m.	86.0	87.5	156.1	157.4	226.9	242.7
6 p.m.	80.5	80.0	135.0	141.2	135.3	146.8
9/12/51						
1 a.m.	59.5	60.5	125.0	127.2	119.2	122.0
7 a.m.	66.5	66.0	137.0	138.6	202.3	204.7

the two fields as shown in table 19. Air temperature 12 inches above the plowed field averaged 0.6° higher for the period shown than over the green field. During the hotter part of the day this difference was 1.5°. Direction of air movement was such that it passed first over the green field so the increase in air temperature occurred as the air moved over 45 feet of the dirt field. Nearby "low-temperature" covers, such as clover or alfalfa, can be very beneficial in keeping down both heat load on an animal and the air temperature. Animals on pasture have this advantage over animals held in a dry lot.

Fig. 44. View of a feed yard using hay shades and cable fences which reduces radiation and allows for greater air movement.

Reduction of Radiation

Three surfaces—sky, corral fences, and surrounding ground—are nearly always "within sight" of cattle in the feed yard and influence the radiation heat load on the animals. Tests reported in this bulletin show that there are practical ways of reducing this heat load.

North Sky. A series of summer sky radiosity observations taken during the last ten years shows that the north sky (about 60° above the horizon) has an average temperature of 20° to 30° lower than ground-air temperature. Any cloud cover will materially reduce the difference between north sky temperature and air temperature near the ground. However, the Imperial Valley has a large number of cloud-free days which make the north sky a fairly reliable source of radiation cooling. Even when the south sky is fairly cloudy, the north sky may be clear because clouds appear to form toward the Gulf of California.

The louver shade, discussed earlier, was one attempt to use the north sky as a cold body to which animals might radiate heat. Even though this test was not successful, the authors feel that this method of cooling should be considered in designing livestock shelters for hot climates.

Corral Material. The better environment in wire or cable corrals was the result of lower air temperature, greater wind velocity, and less radiation. The contribution each of these made toward improving the environment was not determined, but each does contribute to animal comfort.

Tests showed the radiant heat load within a wire pen to be as much as 10 Btu/hr. ft.^{2} less than in a wooden-fence corral, indicating the effect of corral material on radiation. Wind velocity in the wire corral was always greater, and the air temperature averaged about 2° lower. The total effect was a reduction in environmental temperature within the wire pen of 5° to 6°.

Corrals, or cattle pens, should be constructed of wire or cable to permit free air movement and to aid in reducing the radiation heat load on animals and the air temperature in the pen. Also, buildings, haystacks, or any major obstacle should be kept away from a corral to permit free air movement through the area and to eliminate radiation that might be reflected from them to the animals.

Surrounding Crops. Bare ground will radiate more heat than an area planted to a crop. Also, air moving over bare ground tends to become warmer than air moving across a green field. A certain amount of bare ground around corrals is necessary for the roads and alleys, but a crop planted in the vicinity of the feed yard will tend to reduce the air temperature and radiation.

Figure 44 shows a feed yard that has provided cattle with a cooler environment. The hay shades are about 11 feet high, which reduces radiation from the sun and still allows animal exposure to the cool north sky. The corral fence is made of cable, which reduces fence radiation and allows for free air movement. Haystacks and buildings are away from the corrals. Although the photo does not show it, there is a crop planted around the feed yard.

The calorigenic effect of food is much greater in ruminants than in animals with a single stomach. One of the chief maintenance requirements for animals in a cold climate is heat to keep the body warm. Roughages have a much higher relative value for heating the body than they do for productive purposes. For instance, idle horses can be wintered on rather poor quality roughage alone because of the heat produced through its digestion and assimilation. By the same token, a roughage diet during the summer would tend to make the animals hotter at a time when they are having difficulty getting a balance between the rate of heat produced and rate of heat lost.

Heat produced in the body following the consumption of food is known as "heat increment." This is the heat produced in the body by digestion and assimilation of food. As noted above, this heat will warm the body but cannot be used for any other purpose since the body is unable to convert heat into other forms of energy. Even with such easily digested feed as barley, about one-third of the total energy in the digested nutrients is lost in the increment of heat, and the losses with hay and straw are much larger (60 per cent for wheat straw.)

A summary of several tests, some conducted during the summer and others during the winter, with some groups receiving a hay concentrate ration and

Table 20—Comparative gains and estimated gains of summer and winter feeding trials with Hereford steers*

	Alfalfa Hay Summer Warm Water	Alfalfa Hay Summer 65 °F. Water	Alfalfa Hay Winter	Alfalfa Grain Summer Warm Water	Alfalfa Grain Summer 65 °F. Water	Alfalfa Grain Winter
Number of animals	21	20	11	21	21	16
Av. length of trials (days)	77	77	131	75	75	84
Av. initial weight (lbs.)	814	810	662	732	740	810
Av. final weight (lbs.)	890	909	890	849	877	1004
Av. daily gain (lbs.)	0.97	1.27	1.74	1.58	1.83	2.31
Av. daily feed (lbs.)						
Barley	.....	.....	.....	4.4	5.1	6.7
M.D.B.P.§	.....	.....	.....	2.2	2.4	2.8
Alfalfa hay	18.4	19.4	16.0	9.9	10.2	10.6
Oat hay	1.7	1.8	1.8	2.0	2.3	1.9
Total	20.1	21.2	17.8	18.5	20.0	22.0
TDN†	10.26	10.82	9.07	11.10	12.09	13.66
DCP‡	2.14	2.26	1.88	1.69	1.80	1.99
Estimated gain	1.50	1.70	1.50	1.70	2.00	2.20

* All summer feeding was done in the warm environment of the wooden corrals during July, August and the first part of September. Winter feeding was done from January through most of May. Each test includes at least three feeding tests.
† Total digestible nutrients.
‡ Digestible crude protein.
§ Molasses dried beet pulp.

others only a hay diet, indicates the low productivity of cattle on a roughage diet during the summer. Possibly the heat increment of a roughage ration is only a partial explanation of these differences in daily gain. These tests are shown in table 20. Each group is the average of at least three experiments. All of the summer feeding was done in the warm environment of the wooden corrals, which produced lower daily gains than would be the case from animals in the cooler environment of an airy wire corral. Summer tests were conducted from the first part of July to about the middle of September, while the winter tests ran from January through most of May. Animals in these tests were all Hereford steers.

Animals made poor daily gains (0.97 pound) on a hay ration during the summer. Cool water increased these gains to 1.27 pounds and also increased food consumption, but the expected gain based on the food consumption (TDM and DCP) shows that they should actually be gaining about 0.5 pounds more per day. With a hay and grain diet, the daily gains are 1.58 and 1.83 pounds for warm and cool water respectively; only about 0.15 pound less than the expected gain.

During the winter when temperature is not a factor, daily gain for alfalfa hay is 1.74 pounds and 2.31 pounds for the grain-hay ration. These gains are a little above the expected daily gain based on the daily food intake. With a cooler environment than the wooden corrals most animals will make better than 2.00 pounds gain with a concentrate roughage ration. If two animals are receiving 20 pounds of feed a day and one animal gets one-third of this as grain and the other only hay, the one receiving hay and grain would have about 20 per cent less energy to dissipate as heat and 20 per cent more energy to use for productive purposes than the animal on the hay diet.

The animal's efficiency of gain is materially increased during the summer by using a hay and grain diet. Summer gains usually require more feed to make 100 pounds of gain, and daily food consumption is also down during the summer. It is just a little more difficult to keep animals on feed during hot weather.

Although summer diet seems to be a factor in producing faster gains, cattle still present a difficult problem to feeders trying to improve their production in hot weather. Cattle have a high rate of heat production, as shown by the basal metabolism of a 765-pound Guernsey cow 48 hours after feeding, which was 62 Cal./sq. m/hr., while a 35-year-old woman only produced 37 Cal./sq. m/hr. (Worstell and Brody, 1953). Along with this high heat production, cattle have a low loss of heat through moisture vaporization. Cattle seem to react to low temperatures more as arctic species do while man's reactions are like those of tropical species, and there is definitely a basic incompatibility between high productivity and high environmental temperatures for these larger non-sweating animals.

It is surprising to note that cows, when kept in constant-temperature rooms with the heat slowly increased from 80° to 100° F, will show a decline in heat production of 30 to 40 per cent. Part of this decline is due to a decline in feed consumption and milk production, which may amount to 25 per cent of the total heat produced. The remainder may be due to a decline of thyroid activity since rats, a non-sweating animal, have a lower thyroxine production at high temperatures which decreases their basal metabolism (Kibler, Brody, and Worstell, 1949).

At high temperatures, cattle are hard pressed to keep body function going, but at the mean temperature of 90° F during July and August in the Imperial Valley they are definitely more productive on a hay and grain ration than on a straight hay diet, and this is partly due to heat increment.

THE TESTS SHOWED | **That the proper summer diet will help cattle maintain thermal comfort**

A diet high in fiber will produce considerable energy that will have to be dissipated as heat from the animal's body. This phenomenon is much more in evidence in ruminants than in single-stomach animals. Although the heat produced in the body following the consumption of food is very valuable to cattle during cold winters, it is a decided detriment in the summer when animals are having difficulty reaching a balance between heat produced and heat lost. Our tests have shown that using grain and good quality roughages (low in fiber) will allow cattle to make satisfactory gains during the summer. Even when the ration is composed of just good quality roughage they tend to have considerably lower daily gains than would be expected.

In these desert areas of California 2.00 pounds of gain per day or better can be expected during the summer months if proper precautions are taken as to diet, water, corrals, and shade. Even so, food consumption and efficiency of gain are lower when compared to winter production. Some consideration should also be given to having cattle acclimated before summer comes; that is, bringing them into the area before summer starts so they can gradually become accustomed to the heat. It is also desirable to plan a livestock program so that cattle do not reach a high degree of finish during the middle of summer. It would be better to finish the fattening period just before summer weather begins or during the early fall. A heavy layer of fat reduces the animal's ability to rid itself of excess heat.

Costs and Power Consumption

Results indicate that most investments in cooling pay off

In obtaining results reported in this bulletin, costs of the different treatments were considered, but they were not regarded as criteria for evaluating the results. The tests reported were all experimental and the basic objective was to find the effect of different treatments. However, records of costs were kept, and analysis will show that most of the treatments, even as applied experimentally on a small scale, increased the producer's net income. One treatment that did not show an increased return, as applied experimentally, was cooling drinking water by mechanical refrigeration. Although the increase in weight gains was good, cost and upkeep of the equipment offset the value of the increased gains.

Costs must often be rationalized carefully to obtain a true evaluation of experimental results. Cattle drinking cooled water in a hot environment did gain substantially more than cattle drinking uncooled water. Practical application of this result does not necessarily require the large equipment investment used in the experimental tests. Other methods of cooling water by evaporation (page 41) and nocturnal radiation (page 47) were tried. In some cases the problem may not

be to cool water, but to keep it cool. One producer in the Palo Verde Valley, interested in applying these results, was able to get 70° F water from his well, store it in an insulated tank, and pipe it underground to his corrals so it would stay cool. With little additional cost, he was able to supply his cattle with cool drinking water.

Using a fan to increase the air flow over beef cattle during hot weather promoted increased daily animal gains. In this case the cost of the fan and its operation, even on an experimental basis, could very easily be justified by the increased returns from greater production. Even here, the costs involved are not entirely relevant to the value of the results. The tests proved the benefit of increased air flow—the fan was only a means of increasing the air flow. Where location of the enterprise and surrounding structures can be planned and arranged to utilize natural wind, there may be no extra cost involved in applying results of the fan tests.

If equipment is installed to cool the air, cool the drinking water, or to in-

Table 21—Power use of equipment

	Cattle treated	Electric power use—KW Hr.		
		For season	Per day	Per animal day
Cooling air with desert cooler				
1948	7	88	1.63	0.233
Evaporative cooling tower pump				
1951	5	129	1.50	0.300
1954	7	89	1.49	0.213*
Evaporative cooling tower fan				
1954	7	76	2.98	0.426†
Refrigerated drinking water				
1952	20	1131	17.14	0.857
1953	13	786	9.36	0.720
1954	14	846	10.07	0.719
1955	14	996	14.23	1.016‡
Fans in corral§				
1955	7	974	13.91	1.987
1956	7	1207	17.24	2.463

* Pump used to circulate water for first half of 1954 season.
† Fan used to cool water during second half of 1954 season.
‡ Includes energy for cooling extra water consumed by steers on salt water experiment.
§ During 1955 fan was on 12 hours per day for 21 days and continuously for 49 days. Fan was on continuously for 70 days in 1956.

crease the air flow, the equipment cost and maintenance will generally be the largest item of the cost increase for cooling beef cattle—but not always. While for all tests the "cooler" animals consumed less feed per unit of weight increase, their total food consumption was greater than that of the "uncooled animals. Increased cost for additional feed may actually be greater than equipment cost.

The third cost item is power, if it is required. This, however, is generally small. Actual power used in the tests described in this bulletin is shown in table 21. The power used varied from 0.23 kw. hr. per animal per day for the desert cooler to 2.45 kw. hr. for the fan. Average power costs on California farms are usually considered to be 1½ cents per kw. hr., so the power costs in our tests would have ranged from 0.345 cents per animal per day to 3.675 cents. This latter cost is perhaps excessive, but this was for power to run the fan that ran continuously, which was probably unnecessary. Also, the fan probably would have cooled 30 animals instead of 7. Table 21 also shows how much less power was needed to cool water by evaporation than by mechanical refrigeration. The value of "cooling" beef cattle is greatly influenced by the relationship between beef prices and feed cost.

Summer Water Requirements

Cattle with cool water or less thermal stress drank less water

A daily record of water consumption by lots was kept on many of these test animals, especially on the cold drinking-water lots and check groups. Some of these data have already been presented, but a more detailed accounting is desirable since water is such an important part of the animal's body. The engineer is also interested in the water requirements of cattle during the summer. Many of these data are presented in table 22 and show both the average daily water consumption and average daily water consumption per 100 pounds of live weight by periods.

In most cases those animals with cool water, or under less thermal stress, drank less water than steers with warm water or in a warmer environment. As noted above, the use of salt in the ration increased water consumption in both the warm-and cold-water pens, but no benefits could be ascribed to the salt. One pen of Brahmans was fed during the summer (1950) and their water consumption was less than the Herefords even when it was calculated on the basis of gallons consumed per 100 pounds of live weight.

A detailed investigation was made of the times when water was consumed by the cattle during 1950 and has been checked with data collected in later years. The general trend has been the same. All groups of animals drank more water on the warmer days than they did on cooler days. This is especially true of the warm-water Herefords. As a further check on this, the average water consumption on about 20 days, with a mean air temperature of 83° F or less, was compared with the average water consumption on about 20 days with a mean air temperature of 88° F or more. In all cases the water consumption was greater on the hotter days. The warm-water Herefords drank 2.23 gallons per day per head more on the hot than on cool days; the Brahmans 1.30 gallons more; and

the cold-water Herefords only 0.49 gallon more. Several sets of hourly readings of water consumption were taken throughout the test. Most of the water was consumed by the Herefords in two 4-hour periods during the day, 7 A.M. to 11 A.M., and 4 P.M. to 8 P.M. This coincides with the times of feeding, 7:30 A.M. and 5 P.M. Both groups of Herefords drank approximately 1.1 gallons per hour per head during the 4-hour morning period and 1.7 gallons per hour per head in the evening. During the heat of the day, 11 A.M. to 4 P.M., only about 0.4 gallon per hour per head was consumed, and, during the night, when the water was fairly cool, the animals drank only 0.3 gallon per hour per head. The Brahmans drank less than these amounts but followed the same trend.

The water consumption reported in 1950 is roughly double the observed consumption of cool water ($50° \pm 10°$) by non-lactating dairy cows under temperate conditions (data cited by Thompson, Worstell, and Brody, 1949). Thus, the high water intake and the high correlation of water intake with atmospheric temperature variation in this study confirm, under field conditons, the results reported by the Missouri workers as obtained under controlled conditions of their Climatic Laboratory. Ragsdale, Thompson, Worstell, and Brody (1950) found that Braham cows consumed less water per 100 pounds weight below a constant temperature of 90° F. From 85° F upward the Brahmans increased water consumption rapidly and exceeded, with one exception, the Jerseys and Holsteins. One Jersey consumed huge quantities at high temperatures and kept up her production. The other Holsteins and Jerseys tended to decline in water consumption at high atmospheric temperature. These high temperatures were constant temperatures and exceeded those experienced here in Imperial Valley. Water consumption varies considerably from one animal to another, and individual reactions may be significant.

A recent study by Winchester and Morris (1956) gives the water requirements of cattle under a wide range of conditions and diets. They point out that water consumption remains rather constant between air temperatures of 10° and 40° F. As air temperatures increase to 100° F, consumption increases rapidly. Water consumption will more than double with a change in air temperature from 40° to 90° F.

Table 22—Average daily water consumption, gallons per animal, and average daily water consumption, gallons per 100 pounds of live weight

Period of experiment	Per head	Per 100 lb. weight	Per head	Per 100 lb. weight	Per head	Per 100 lb. weight
1950	Cold water 65°		Warm water 88°		Warm water 88°*	
Preliminary:† May 24–June 13	16.9	2.09	15.6	1.97	....	....
First, June 14–July 11	15.9	1.83	16.1	1.90	9.7	1.60
Second, July 12–August 8	15.1	1.65	16.6	1.89	9.9	1.52
Third, August 9–September 5	15.6	1.64	17.7	1.95	10.7	1.60
Average: June 14–September 5	15.4	1.69	16.6	1.89	10.0	1.55
1952‡	Cold water 65°		Cold water 65° and showers		Warm water 90°	
First, July 2–July 29	13.3	1.72	14.2	1.83	14.5	1.88
Second, July 30–August 26	13.2	1.64	13.8	1.73	15.0	1.90
Third, August 27–September 11	13.8	1.67	14.0	1.71	15.8	1.94
Average: July 2–September 11	13.4	1.68	14.0	1.75	15.0	1.88
1953§	Cold water 65° and hay		Cold water 65° hay and grain		Warm water 89° hay and grain	
First, June 30–July 27	12.6	1.42	11.6	1.27	13.3	1.49
Second, July 28–August 24	14.2	1.54	10.5	1.09	12.9	1.40
Third, August 25–September 22	14.0	1.45	11.6	1.14	12.6	1.30
Average: June 30–September 22	13.6	1.46	11.3	1.17	13.0	1.38

1954§	Water 86°; fed pellets**		Water 81°; fed pellets			
First, June 24–July 21	12.4	1.50	9.4	1.13	....	....
Second, July 22–August 18	12.0	1.39	10.3	1.16	....	....
Third, August 19–September 16	13.0	1.41	11.6	1.22	....	....
Average: June 24–September 16	12.5	1.42	10.5	1.17	....	....
1955§	Water 60°; hay and grain		Water 70°; hay and grain		Water 87°; hay and grain	
First, July 6–July 26	12.0	1.75	11.7	1.72	12.3	1.82
Second, July 27–August 16	10.6	1.48	10.5	1.47	12.2	1.75
Third, August 17–August 30	10.6	1.43	10.9	1.45	12.6	1.74
Fourth, August 31–September 14	10.4	1.34	11.0	1.40	12.8	1.72
Average: July 6—September 14	10.9	1.50	11.0	1.50	12.4	1.74

* Four head of Brahman steers averaging 644 pounds on alfalfa hay in 1950.
† Both lots of Herefords drinking warm water, 4 head in each pen.
‡ Ten Hereford steers in each pen, fed alfalfa hay.
§ Seven Hereford steers in each pen, 1 died in 1953 in cold water hay and grain lot.
** Pellets = 35% barley, 15% molasses dried beet pulp, 35% alfalfa hay, 15% oat hay.

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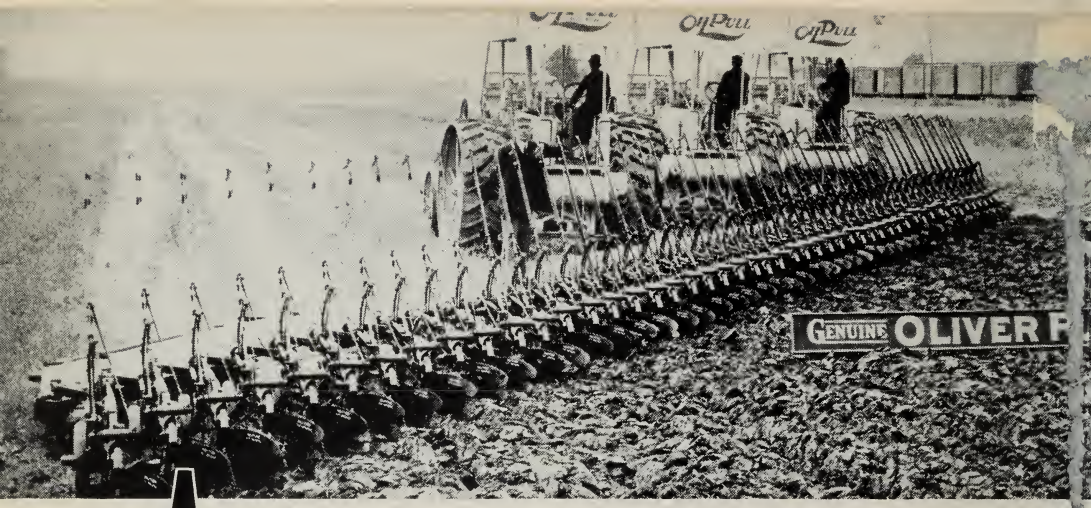

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